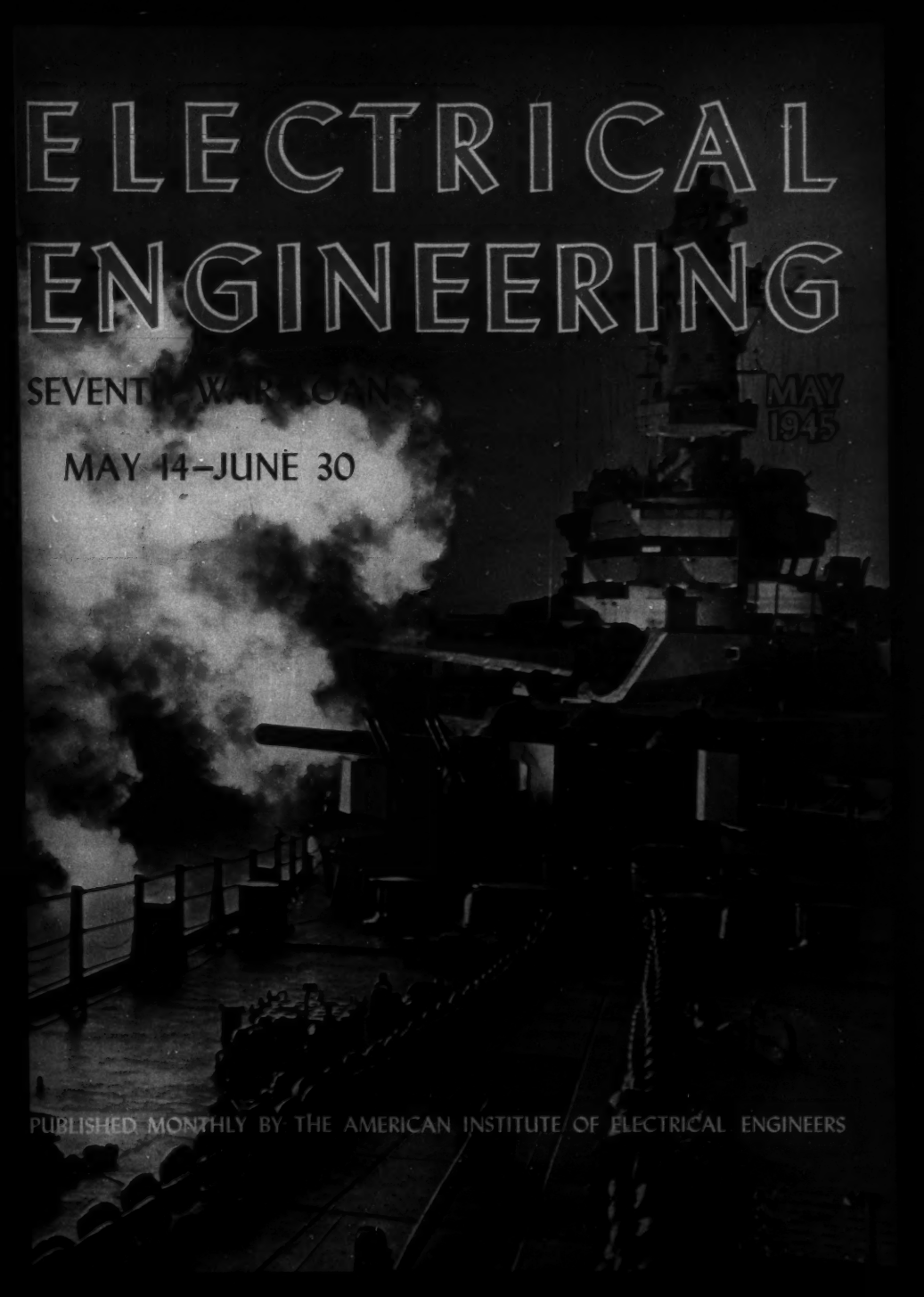
ELECTRICAL ENGINEERING

SEVENTH WAR LOAN

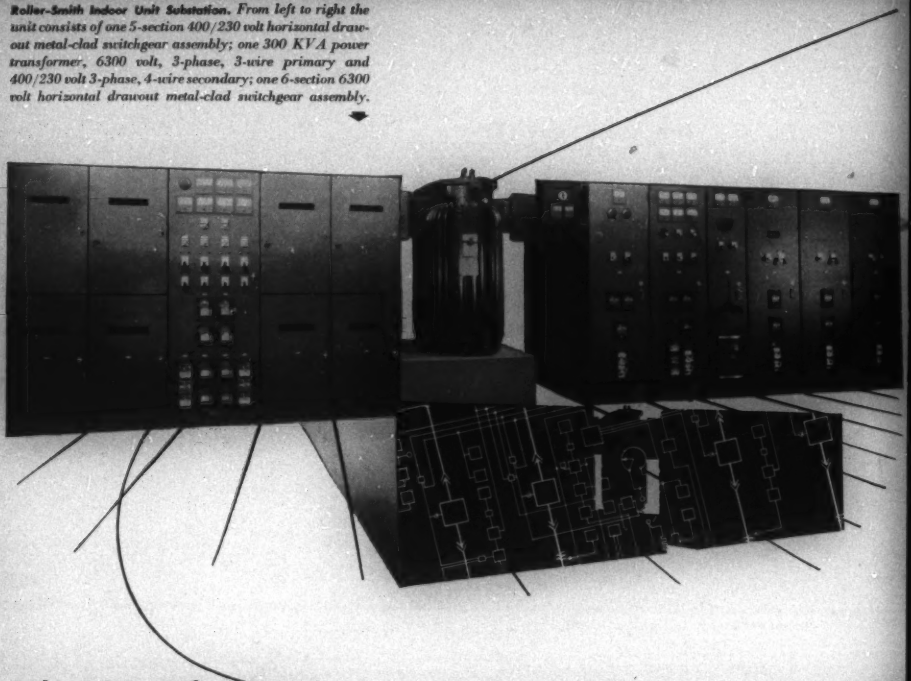
MAY 14–JUNE 30



MAY 1945

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Roller-Smith Indoor Unit Substation. *From left to right the unit consists of one 5-section 400/230 volt horizontal drawout metal-clad switchgear assembly; one 300 KVA power transformer, 6300 volt, 3-phase, 3-wire primary and 400/230 volt 3-phase, 4-wire secondary; one 6-section 6300 volt horizontal drawout metal-clad switchgear assembly.*



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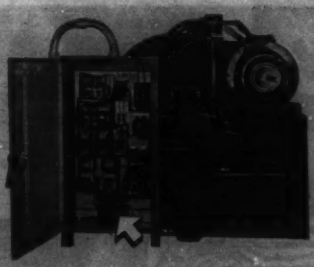

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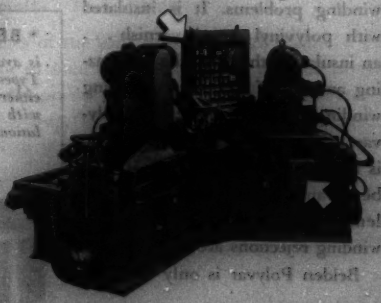

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Now—for the first time—an insulating varnish is available that approaches Fiberglas, mica and asbestos in ability to resist heat, moisture and corrosive fumes. This new varnish is DC-993—a member of the new chemical family of SILICONES.

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DC-993 is the member of this new silicone group that is best suited for use as an insulating varnish. DC-993 is a joint development of Dow Corning chemical research and Westinghouse "know-how".

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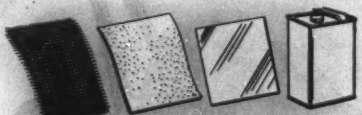
In DC-993, the carbon skeleton of the resin is replaced by a chemically inert silicon. So, in DC-993, we have an insulating material that approaches Fiberglas, mica or asbestos in ability to resist heat, moisture and corrosive fumes.



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DC-993 is applied by dipping, spraying or brushing like any ordinary insulating varnish—the only difference being, a baking temperature of 250 deg C (482 deg F) is required to set DC-993.

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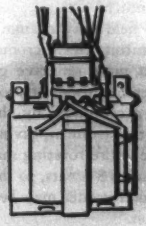
3 Greatly increased protection from moisture and chemical laden atmospheres . . . because DC-993 is inert and does not become cracked or crazed after long service.

Proof—The improved insulating values of DC-993 have been proved both in laboratory tests and in service.

For instance—In one laboratory test, magnet coils insulated with DC-993 have been in operation over 10,000 hours at an observed temperature of 275 deg C (552 deg F).



For instance—A large number of magnet coils of various types insulated with DC-993 are in operation on street railway controls and records indicate a life considerably longer than Class B insulated coils.

For instance—A generator insulated with DC-993 ran 3000 hours at a temperature of 250 deg C (482 deg F), equal to a tremendously longer life at a normal operating temperature than obtainable with any other insulating varnish.

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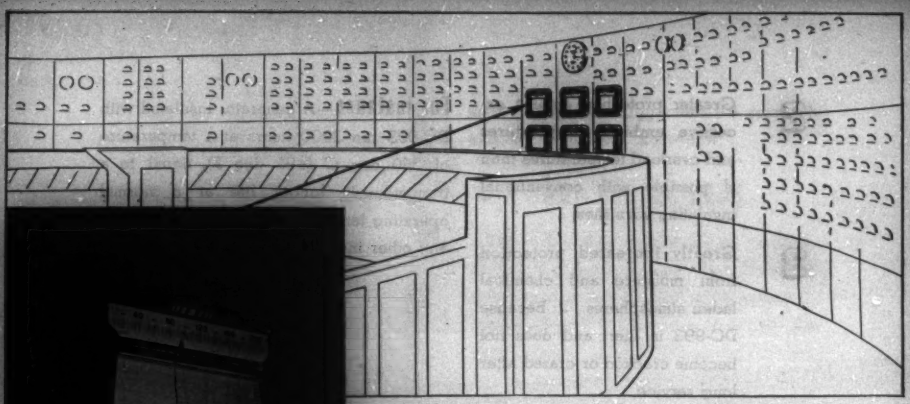

The Record of a Micromax Helps With Overloads

When war work causes big generators to approach an overloaded condition (as many now do) the operating engineers are finding a new use for the Micromax Recorders of stator and rotor temperatures. They are watching temperature as never before, because it is temperature which eventually limits the load piled on a machine. When a change in power factor or ambient temperature permits a load increase, the stator and rotor temperatures are watched to say . . . how much!

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The fact that the stator temperature does move more deliberately, however, makes many engineers prefer it as an operating guide, and complete protection against overheating requires that both field and stator recorders be the "insurance policy." They are equipped for signal lights and horn or bell, and stand always ready to give overall protection to generators, whether they be heavily loaded—or overheated by accident.

Both of these Micromax Recorders are described in Catalog N-33-161, "Micromax Temperature Instruments for Electric Power Equipment," which is sent on request.

[Tri Ad N-33-161(6)]

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ELECTRICAL ENGINEERING

Registered United States Patent Office

MAY
1945

The Cover: Main battery salvo of USS *Missouri*, 45,000-ton superdreadnaught, showing the three 16-inch guns of number-2 turret as seen from the bow. This is the fourth of the mighty *Iowa* class ships to be commissioned. Official United States Navy photo

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ELECTRICAL ENGINEERING
VOLUME 64, NUMBER 5 MAY 1945

Army Ground Communication Equipment

ROGER B. COLTON

The requirements for combat communication equipment, some of the problems in its development and production, and the testing and observation of it in actual operation in the field are recounted in this article. Wire, switchboards, radio equipment, types of control, and carrier systems are discussed.

THE ARMY, in communication work, uses two fairly distinct types of equipment—fixed-type communication equipment and combat-type communication equipment. The so-called fixed type of equipment corresponds, or at least initially corresponded, very closely to normal commercial communication equipment with which we are all familiar and have been familiar for many years. Combat-type communication equipment, on the other hand, is in many respects entirely different from ordinary commercial communication equipment, although there has been a tendency throughout the course of the war to introduce some of the features of normal commercial equipment into the combat equipment and likewise to replace the fixed communication equipment, ordinarily used by the Army in the rear areas, to a considerable extent by combat types of equipment.

When war became imminent in 1938 or '39, Congress made some considerable preparations in the way of providing for development and even for production of those items of military equipment which are associated in most people's minds with military operations: namely, such things as airplanes, naval vessels, artillery cannon, small arms, and explosives. There was not, however, a general recognition of the fact that combat communication equipment is a highly specialized weapon and that development in advance and procurement in advance of such equipment was necessary if the Nation was to be prepared for war. This lack of appreciation of the importance of specialized military communication cannot be charged to any one person or persons either in the Army or out. It may, however, be stated as a fact.

The initiation of extensive Army maneuvers in 1939 and 1940 brought to the attention of all concerned the necessity of providing special combat communication equipment as well as many other special items of military equipment not in the so-called armament classification. Consequently, in June of 1940, considerable funds were appropriated for the development of combat communication equipment. Those of us in the Signal Corps and the communications personnel in the various using arms, such as the Infantry, Cavalry, Field Artillery and Antiaircraft Artillery, of course were convinced of the necessity for the best possible combat communication equipment and had not been idle during the preceding years. In anticipation of that day when the necessary funds might be provided and also with a view to creating sufficient interest to insure that adequate funds would be provided eventually, beginning in 1938 we had drawn up at the Signal Corps Laboratories, Fort Monmouth, N. J., a series of five-year plans for the development of a complete line of equipment and had circulated these plans where they would do the most good as an effective planning tool. The funds estimated in these plans were very modest indeed but were, generally speaking, initially considered by those who read them to be fantastic.

In connection with this program a demonstration of all available types of signal communication equipment was arranged at Fort Knox, Ky., November of 1939. During and immediately following this demonstration, Lieutenant Colonel Louis B. Bender, Major Hugh Mitchell, and Captain David E. Washburn, from the research and development division of the Office of the Chief Signal Officer and the personnel of the Signal Corps Laboratories at Fort Monmouth contacted those agencies of the using arms that had cognizance of communication development. As a result of this action, by January 1940 we had a fairly definite and also a very moderate program for the development of equipment largely agreed upon, and as a result of the imminence of war Congress appropriated considerable funds in June of 1940.

These funds became available to the Signal Corps Laboratories in August, and we then were faced with the necessity for developing and putting into production at the earliest possible moment the new items of communication equipment. As of that date the entire personnel of the Signal Corps Laboratories at Fort Monmouth, N. J., consisted of eight officers and 148 civilian employees. The following personnel was charged with the responsibility of development of ground signal equipment as indicated:

Colonel R. B. Colton, director of laboratories
Captain J. D. O'Connell, executive officer
Lieutenant A. F. Cassevant, on detail from Coast Artillery Corps

Project Officers:
Captain Reginald Lyman
Captain J. D. O'Connell
Captain R. V. D. Corput, Jr.
Captain Oscar C. Maier

Section Chiefs:
G. A. Graham, wire communication
W. S. Marks, vehicular radio
J. Hessel, field radio
O. White, automotive and power
R. H. Noyes, product engineering

Liaison Officers:
Captain Stewart Beckley, Field Artillery
Captain Dana McBride, Cavalry
Major Ernest J. Barker, Infantry

Though not actually on duty with the Signal Corps Laboratories, Major Grant A. Williams, then signal officer of First Mechanized Cavalry and now signal officer of First Army, pioneered Armored Force communications and worked closely with the laboratories.

The proportion of the total possible personnel available for work on the communication program at that time amounted to approximately one fifth, or two officers and 30 civilians. It was necessary therefore rapidly to expand our personnel and at the same time to inaugurate a large development program.

In the years preceding the imminence of war, the Army (neglecting overseas garrisons) consisted of some half-dozen Regular Army divisions, few, if any, of which were completely up to strength, and perhaps a half-dozen National Guard divi-

Essential substance of an address presented at a section meeting of Institute of Radio Engineers, September 28, 1944, in Dayton, Ohio.

Major General Roger B. Colton former chief of the engineering and technical service of the Signal Corps, United States Army, Washington, D. C., is air communications officer, Headquarters, Air Technical Service Command, Wright Field, Dayton, Ohio.

tions. There was a considerable number of service and technical troops, but these were scattered throughout the country at some 200 military posts, camps, and stations, and were in effect principally local housekeeping detachments. Corps and army organizations did exist, but they existed almost entirely on paper. As a consequence, as might be expected, specialized combat equipment had been provided essentially only for divisional troops, and even in the case of divisional troops the equipment provided was inadequate in quantity and though good was of rather old design. There was in existence one battalion called the 51st Signal Battalion, which at that time provided the only field unit that could be used for line-of-communication signal work.

TELEPHONE EQUIPMENT

First, as regards telephone equipment, we had the *EE*-8 field telephone which had been designed at the Signal Corps Laboratories in co-operation with commercial telephone-manufacturing companies. The development of this telephone was essentially completed in 1938, and it was therefore quite modern and up-to-date and has stood the test of the war without any major modification. It is still the best field telephone in the world.

The wire being used at this time was known as 110-*B*. This wire had been developed in the period between the wars by the Signal Corps Laboratories in co-operation with the wire manufacturers, and it too has stood the test of war. I cannot say that it is still the best field wire in the world, because many shortages during the early part of the war forced the Signal Corps to make substitutions which have degraded the wire to some extent. The lack of stranding machines in this country forced us initially to accept wire with parallel lay, and as a result some of our original wire occasionally failed, owing to the individual strands kinking and therefore being very near to the surface of the insulation. The shortage of rubber also forced us to accept the minimum possible amount of rubber in the insulation of the wire, and the change from natural rubber to artificial rubber in the past year has done the wire no good. Nevertheless, this wire has proved to be sufficiently good for military use.

Radio engineers may think that wire is a simple and prosaic object. However, when one considers that at the present time we are producing approximately 1,000,000 miles of 110-*B* field wire per month and still are barely able to satisfy demands from the fighting fronts, one realizes that it is of the utmost importance to the Signal Corps.

In August 1940 for switchboards we had the *BD*-71 and *BD*-72 which are 6- and 12-drop monocord switchboards used principally in the regiments. These boards are in effect the World War French monocord switchboard *BD*-9 and *BD*-11, but in a different housing and having an operator's head and chest set added. They are simple sturdy boards and have given satisfactory service throughout the war. They are, however, heavier than need be by perhaps as much as 50 per cent. These boards could and should have been redesigned early in the war, except for the fact that there were so many other problems of greater urgency to be handled.

The division switchboard of this era was the *BD*-14, a very good World War switchboard, but somewhat antique in design and unnecessarily heavy for the service it renders. It was not considered satisfactory to the using arm (in this case, the Signal Corps) and was one of the pieces of equipment that needed to be redesigned immediately.

For a corps switchboard at this time we had in process of development but not yet developed completely the *BD*-89 developed by the Signal Corps Laboratories, and in the same category for the Army we had the *TC*-1 also developed by the Signal Corps Laboratories based on a Western Electric rural telephone design. In the case of these boards, our problem was largely one of getting them ready for production, and the boards have given good service throughout the war.

For laying and recovering field wire, there was at this time, already recently developed and in production, the reel unit *RL*-26, and this reel unit has given satisfactory service without major change.

At this point it will be appropriate to discuss the difference between commercial and combat wire equipment. First, as regards the field telephone, substantially all commercial telephones are of the common-battery type and are designed for either wall mounting or desk operation. Common-battery operation is not feasible in the field on account of the reduced distance over which such lines can be operated as compared with local-battery lines. Furthermore, in the field, telephones frequently must be used on a point-to-point basis rather than on a central-switchboard basis. However, in many cases even smaller units are located temporarily in situations in which service is obtainable from common-battery exchanges. Therefore, it is at least advisable, if not necessary, that the field telephone be capable of being operated on either common battery or local battery. If we add to these requirements the requirement that the telephone shall be of such shape and weight as to be carried conveniently by the soldier and so rugged that when thrown into a truck it will operate again, it is evident that, while no new principles are involved in the design of the field telephone, new and novel engineering techniques were evolved which resulted in lighter weight and improved performance. The individuals who ate and slept with these wire problems were Major Washburn, Captain Lyman, Mr. Graham, Mr. Wyly, Mr. Tapper, Mr. Parmer, Jefferson Davis, and Byron Anderson.

The requirements for field wire are that one should be able to talk a long distance over the wire, and yet it must be sufficiently strong to permit its being laid from a truck with the consequent inevitable stresses that occur in this manner of laying. It is also subject to being run over by trucks, tanks, and other vehicles. Furthermore, since it is required in large quantities, it must be as cheap as it is possible to make it. As a result, field wire is made of four strands of

Signal Corps photo

Figure 1. Corporal William H. Godfrey, Technical Sergeant Clifford J. McCarthy, and Sergeant Troxy R. Barker operate liaison sets on an airfield somewhere in England

steel wire, 0.013 inch in diameter, two strands of copper wire 0.013 inch in diameter, and one strand of copper wire 0.014 inch in diameter, with a rubber insulation 0.026 inch in wall thickness and a cotton braid on the outside. Two such wires twisted three turns per foot form *W*-110-*B* field wire.

For the smaller types of switchboards the required military characteristics are light weight, simplicity of operation, high traffic-handling capacity, and sturdiness of design. The omission of the storage battery ordinarily used in common-battery systems makes for lightness of weight. Simplicity of operation is obtained in the *BD*-71 and *BD*-72 by attaching to each jack or line unit its own cord and plug. The use of a separate cord and plug for each jack or line unit also meets the other needed military characteristics of high emergency traffic load by providing 100 per cent cord circuits. As regards the switchboards to be used by divisions and higher units, the requirements are again relative lightness of weight, high traffic handling, and sturdiness of design. However, in the division switchboard we provide four trunk circuits for connection to common-battery exchanges, and 40 magneto lines, while in the corps switchboard we provide 37 common-battery lines and 20 magneto lines and in the Army switchboard 60 common-battery lines and 30 magneto lines. For rear-area use we use standard commercial common-battery telephones, and, while we provide on division, corps, and army switchboards provisions for interconnection with automatic exchanges, our combat equipment has no automatic exchange features other than necessary dials and relays to permit this interconnection.

One of the major contributions in the field of telegraph- and Teletype-switchboard design was the development of the switchboard *BD*-100 designed by Mr. Parmer of the Signal Corps Laboratories. This is one of the lightest-weight and most trouble-free switchboards used in the theaters. It is a ten-line Teletype switchboard, neutral operation, with facilities for connecting three boards in multiple. It is used in connection with standard teletypewriter sets *EE*-97-*A* and has a maximum flexibility for field Teletype operation.

Much emphasis was placed on the fact that the primary means of communication was wire. This is still true—the primary means of signal communication is still wire, but, with the substitution of motor-drawn vehicles for the horse, and with the advent of the tank, there occurs a decisive point early in the campaign—a time in which it is no longer possible to keep up with the advancing forces by means of 35-foot poles and ten-pin crossarms in combination with 110-*B* field wire, which were the prewar means of wire communication.

Consequently, early in the war we began the development of a link to go in between the fixed-pole line construction, which is most suitable for rear areas, and

Signal Corps photo

Figure 2. This soldier with his switchboard is in a "king-size" foxhole putting through a telephone call under combat conditions. This is not a combat zone, however, but the area around Goldsboro, N. C., where units of the antiaircraft artillery school, Camp Davis, N. C., work out field problems

the relatively light field-wire construction, which is most suitable for the advance element. These two systems were the radio-relay carrier system and the spiral-four carrier system. We had the experience of the English to go on in the matter of the spiral-four carrier systems, and it was not too much trouble to convince our operating personnel of its utility.

The spiral-four system comprises spiral-four cable and *CF*-1 and *CF*-2 carrier equipments. The spiral-four cable consists of four spirally wound conductors with a common metallic-foil shield used as a common ground return having balancing coils and capacitors at quarter-mile intervals, thus loading the cable uniformly as a transmission line. *CF*-1 carrier equipment provides four voice-frequency channels over the spiral four. The addition of the *CF*-2 carrier equipment provides four telegraph channels over one of the voice channels mentioned previously. It is of interest to note that the production to date of *CF*-1 and 2 carrier equipment exceeds all *C*-, *H*-, and *K*-type carrier in use by the Western Electric Company and the American Telephone and Telegraph Company by 100 per cent. Later I will discuss the application of this same carrier system in conjunction with radio-relay systems.

As the major items of radio equipment in use by our field troops in 1940 we find the *SCR*-131, 161, 171, 193, 245, 194, 195, and 177. The *SCR*-131, 161, and 171 were all continuous-wave telegraph master-oscillator sets. These sets were perhaps good enough sets, their design being only five to ten years old, but since the time of the initiation of their design tactical operations had so changed that telegraph communication within the lower units, for which these sets were designed, was no longer a practical method of communication. It was, therefore, necessary to replace these three sets with simply operated voice-frequency sets.

The *SCR*-193, which has the *BC*-191 transmitter (the same transmitter used in aircraft) and the *BC*-312 superheterodyne receiver, was somewhat old in design, the transmitter having been originally used on the Dole-Hawaiian flight in 1928. However, this transmitter was an item of aircraft equipment, and therefore money had been obtained for its redesign and improvement. Furthermore, so many transmitters had been built for aircraft use that all the bugs had been taken out of it. It was, however, a master-oscillator power-amplifier job and could not be netted without the use of a crystal-controlled frequency meter. The receiver that went in this set was a superheterodyne designed by the Signal Corps Laboratories that has stood the test of the war without major modifications. In fact, although we considered it necessary to replace the *SCR*-193 radio set, both transmitter and receiver, with the *SCR*-506, a modern radio set having 20-kilocycle crystal calibration points, four preset channels and one selective channel, our failure in this case to produce our new development in as good time as the rest of our developments does not seem to have affected our communications seriously. This is one case in which an old reliable of rather obsolete design has continued to give most excellent service. The 506 was designed for us by the General Electric Company. Captain O'Connell and Mr. Marks of the Signal Corps Laboratories contributed in an oustanding manner to the development.

The *SCR*-245 was of somewhat later design than the *SCR*-193 and had provisions for crystal control. However, it had only ten watts output and therefore was suitable only for relatively short-range work. Furthermore, although provision was made for crystal control during the life of this set, it was not possible to convince the using arms that crystal operation was desirable in this type of field equipment.

The *SCR*-194 and *SCR*-195 (the original walkie talkie) worked on by Captain Corput, Captain O'Connell, and principally by Mr. Hessel, were modern high-frequency superregenerative transceivers in the frequency band 28 to 65 megacycles.

The problem confronting the Signal Corps insofar as radio-communication equipment was concerned was to replace the tactically unsatisfactory and technically rather obsolete radio sets *SCR*-131, 161, and 171 for use within the regiment, to design a more suitable replacement for the *SCR*-193 for regimental and divisional use, and to provide a new mobile long-range vehicular radio set suitable for the so-called "blitz" tactics that occur from time to time in modern mechanized warfare.

Considering both wire and radio communication, the problem was to provide mobile communications to follow up divi-

Signal Corps photo

Figure 3. Radio Operator T/5 Howard R. Schneider at work on the SCR 543, Mignano area, Italy

sional troops using, where necessary, a combination of radio and wire.

In addition to the physical characteristics pertaining to combat communication equipment, there is another and most important factor in the design of communication equipment for combat use. That is the fact that the military communications necessarily must be organized on a command basis rather than on a common-user basis, that is to say, if we are to hold a commanding officer responsible for the operations of his command, we must furnish him with the necessary equipment with which to set up a communication system through which he will exercise command, and we must give him control of that communication system, because it is only by control of that communication system that he is enabled to conduct his operations.

This is not the case in commercial communications. In Dayton, Ohio, for instance, there is one telephone company that serves all of the people in Dayton and undoubtedly serves them most efficiently. This is true, because under peacetime conditions, since operations are very largely stabilized and since cheapness of service is a major factor, the communication system can be carefully laid out long in advance to provide efficient service to everyone concerned.

MILITARY ORGANIZATION EXPLAINED

In war, however, the commander must take into battle with him all of the equipment that he will need in battle and must rearrange and reorganize this equipment to meet his needs of the moment. For this reason military communications systems are organized to follow the chain of command; that is to say, we have the company communication system, which is operated by the company commander and which radiates from his headquarters.

Likewise, the battalion commander has his communication system which radiates from his headquarters down to the company headquarters. Similarly the division commander has his communication system which radiates from his headquarters down to the regimental headquarters. The corps communication system and the army communication system are organized in similar fashion.

Thus it is, generally speaking, difficult and sometimes impossible for the commanding general of an army to call up a platoon leader and tell him how to conduct his platoon during battle, and there is no need for such a conversation to take place, while there is every need for the company commander to be able to call up his platoon commander and tell him what to do next, and, since this need exists, the company commander must have the means to carry it out. It is obvious that no common-user system under the control of a single-battle-theater signal officer would be satisfactory to the company commander. However, in the rear areas the situation is generally more stabilized, and it generally will be found that greater and greater use is made of the common-user principle.

Taking up now the new front-line radio sets developed in this war, I will mention first those developed for the Armored Force: namely, the *SCR*-509/510 series and the *SCR*-508/528/538 series. The requirement here was for vehicular sets of range about three miles in the case of the 509/510 series and about ten miles in the case of the 508/528/538 series. The 508/528/538 problem was taken up with Mr. Lack and H. W. Ritter of Western Electric Company and Mr. Nelson and Mr. Nordahl of Bell Telephone Laboratory by Captain O'Connell, Mr. Marks, Mr. Ross, and Lieutenant Pollock of the Signal Corps Laboratories. In view of the need for rapid communication incident to modern front-line warfare, voice communication only was indicated, and furthermore it was necessary that communication be obtainable instantaneously and reliably. The main things to be decided were the frequency band, and type of modulation, the power output, and the number of readily available channels.

SELECT SUITABLE FREQUENCIES

As regards the most suitable frequency, we had two good leads. Over a period of several years we had had experience with the very low-power (perhaps one-tenth watt) radio sets *SCR*-194 and 195 in the band 28 to 65 megacycles, and, furthermore, we had run a series of tests over the band 2 to 80 megacycles in the fall of 1937 and spring of 1938 to determine the most suitable frequency for short-distance work. We also had the experience of the various city-police systems operating on 1.5 megacycles, 2 megacycles, and 38 megacycles. Strangely enough our experiments in 1937 and 1938 indicated that for vehicular communication purposes equally good results were obtainable on any frequency from about 2 to 80 megacycles if man-made interference was absent.

While I do not pretend to say exactly why this was found to be the case, nor even to argue very strenuously that it is the case, it may well be pointed out that such a result is not inconsistent with practical engineering facts that are well known to all of us. Since the practical height of an antenna on a vehicle is limited to 15 feet, the antenna efficiency of a set at only two megacycles is very low, whereas the antenna efficiency at 80 megacycles is very

high. On the other hand, the transmission characteristics at 80 megacycles are such, at least theoretically, to give line-of-sight transmission, whereas transmission on two megacycles tends much better to hug the ground and to get over the hills and down into the valleys. Nevertheless, even two-megacycle transmission is to a certain extent optical when compared with still lower frequencies, and 80 megacycles is not high enough to be wholly optical, and transmission at this frequency is also helped by the scattering effect of trees and irregularities of the ground and reflection from various and sundry objects. The net results of this is that the best vehicular frequency in the band 2 to 80 megacycles is determined very largely by the relative absence of radio interference on any given frequency.

Tests made during the period 1937 to 1940 indicated that from 2 to 20 megacycles interference from stations thousands of miles away was very severe. In the region 20 to 24 megacycles we found that there was still considerable interference, but we believed and it has since been proved that this band is quite usable for short-distance low-power communication. From 24 to 28 megacycles there was almost an entire absence of interference. Since we already had radio-communication sets for ground troops in the band 1.5 to 5.5 megacycles and in the band 30 to 55 megacycles, we selected the band 20 to 28 megacycles for the Armored-Force sets. We had a little doubt as to the excellence of communications in this band, in view of our transmission experiments and in view of the excellent communications being obtained on 38 megacycles by police radio equipment that had recently been introduced in a number of cities and in the Connecticut State Police system.

Signal Corps photo

Figure 4. T/4 David Kimmel with the United States First Army handles the switchboard where fire-direction orders are sent to two platoons on the line in Hurtgen Forest, Germany. Direction changes from the observation post also come through this board

FREQUENCY AND AMPLITUDE MODULATION

As to the type of modulation to be used, we were in somewhat of a quandary. Some of our people had witnessed a demonstration of frequency modulation given by the General Electric Company in 1938 and were convinced that this was a superior type of communication for military vehicular use. Frequency-modulation equipment also had been introduced in the Connecticut State Police system and was being considered by some of the larger cities to replace amplitude-modulation communication equipment.

For the 1939 demonstration at Fort Knox, which I have previously mentioned, Major Armstrong had furnished us with some frequency-modulation communication equipment, and we had built at Fort Monmouth Laboratory a 50-watt frequency-modulation transmitter to give as good communication as ten watts of amplitude modulation. Nevertheless we thought the frequency-modulation principle to be sound and continued the development during the fall of 1939 and during the spring of 1940 to the extent that we were able to do so with the few thousand dollars that we had.

In view of our uncertainty, we decided to proceed initially with the 508 series of sets on the basis of amplitude modulation, but immediately to make a comparative test of amplitude- and vehicular-modulation short-range sets. This test was made during the week of March 24 to April 2, 1941, and the results of the tests showed that frequency modulation in military vehicular application gave 50 per cent more range than amplitude-modulation equipment and up to midrange gave 100 per cent better communication. We had been somewhat concerned as to whether the so-called capture effect of frequency-modulation equipment would be a serious defect. However, we laid this ghost by actually trying out the capture effect. Since actual experiments, conducted under very well-simulated field conditions, showed this effect for military purposes to be practically nonexistent, we were much relieved and went ahead with frequency modulation.

At a later period in 1942, this question as to the value of frequency modulation was raised again by our Allies. Extensive day and night tests were held at the Harrison Farm, N. J., comparing the operation of preset mechanical-tuning 2–8-megacycle amplitude-modulation sets with our 20–28-megacycle frequency-modulation crystal-controlled sets. Witnesses of the tests were members of the British Military Mission, the Army Communication and Equipment Co-ordination Board, Ground Forces, the Chief Signal Officer, and representatives from the various staff divisions of his office. Tests were run during thunderstorms and pouring rain. These tests were supervised by Lieutenant Colonel Maier of the Signal Corps Laboratories and Colonel Elsdale of the British mission. The only open question remaining was operation over really rugged country and the effect of sunset and sunrise fading. Tests were held at Bethlehem, Pa., over a triple range of mountains covering the periods of dawn and sunset during the month of November of 1942. These tests were witnessed and recorded and proved conclusively that the frequency-modulation sets were the best.

This transmission problem is still being argued out in other circles on a theoretical basis with diminishing emphasis. So far as I am concerned there is no argument left, because we now have had approximately 200,000 frequency-modulated sets in satisfactory operation in bands above 20 megacycles.

As I have stated one of the problems that confronted us at this time was to decide the type of frequency control to use. It had been axiomatic in the military service that radio sets must be simple and rugged. It had also up to this time been axiomatic in both military and commercial circles that crystals were relatively unobtainable jewels of great price.

CRYSTAL-CONTROLLED SETS PROVIDED

Furthermore both the Navy and our Air Corps had tried combat types of crystal-controlled radio sets and had found them unsatisfactory. Having followed this problem for some years, I became convinced that the crystal-controlled sets had been unsatisfactory in the Navy and in the Air Corps, principally because not enough crystal-controlled channels were provided in each set and because crystals for all channels were not provided with each set. We, therefore, decided to provide ten preset crystal-controlled channels in each transmitter and to furnish 80 crystals with each transmitter.

At this time, we were fortunate in dealing with a man who believed in frequency modulation and who believed in crystals, namely, Fred Lack of the Western Electric Company. I am glad to say that Mr. Lack and his organization delivered an amplitude-modulated model of the 508 in

February and a frequency-modulated model in March of 1941 and actually started the wheels of production rolling before the set was formally standardized and all this before a contract of any kind had been approved.

Simultaneously with the Western Electric development of the *SCR*-508 our own laboratory engineers under Captain O'Connell, Mr. Hessel, and Mr. Morf proceeded with the development of the *SCR*-509, a frequency-modulation set with two preset crystal frequencies and 40 crystals in the same band as the 508 (20–28 megacycles), and, after completion of the design, this set was put in the good hands of Doctor Noble and the Galvin Manufacturing Company for production.

A further statement on crystals is in order. In World War I there was no mass production of vacuum tubes. They were handmade and nonuniform in operation. Our type numbers were formed from them; namely, the *VT*-1 and 2. The first miniature tube was the *VT*-5. By the end of the war, they were being produced by the tens of thousands. In this war, crystals were being produced on a hand-to-mouth basis by just six suppliers, all of whom considered the art a fine art and to be paid for accordingly.

Naturally, to implement the idea of crystals for every channel, aggressive steps were in order to provide the necessary quantity of crystals. With the help of civilian specialists and personnel who did not believe in superstition, such as Doctor D'Eustachio, Miss Grady, Major Woods, Captain Mitchell, Mr. Bell of War Production Board, Mr. Buff of Metals Reserve, Colonel O'Connell, Mr. Parrish of the Office of the Chief Signal Officer and later Doctor Van Dyke and Major Swinnerton, a crystal school for manufacturers was set up at the Steinbach Building, Long Branch, N. J., and a crystal-sorting plant at Bethlehem, Pa., was established, with the result that ultimately we obtained 14 crystals per pound from 30 per cent or better-quality quartz as against one crystal per pound at the peacetime level. The Bliley Company gave whole-hearted support to producing smaller crystals, and furnished us the first *FT*-243's. Bell Laboratories, under Doctor Bauer, and D. K. Martin, became enthusiastic over the *FT*-241. The crystal business was conducted from well-equipped shops to individual operators working in their houses throughout the farm lands of Pennsylvania, finishing crystals.

The crystal production today in one day equals the total annual crystal production in 1939. The number of crystals produced begins to approach the vacuum-tube production. The uniformity and accuracy of military crystals compared extremely well with industrial precision-ground crystals prior to the war. It was at this time that we had missionaries on the road with portable oil baths, X-ray machines, instruction books, and so forth, to preach the gospel of mass production of crystals. We all know the story now. To date the Army has spent $200,000,000 for crystals.

Mr. Galvin likes to tell the story that when selected as the manufacturer of the *SCR*-536 set he asked how he was to get the crystals, I told him he was an industrialist and that it was up to him to be industrious, not me. Well, he has been quite industrious and since that date has delivered millions of *FT*-243 crystals (with the help of 20 subcontractors) to the Army. However, it is well to mention the Western Electric Company who has delivered more than half as many *FT*-241 crystals from their own shops.

These sets, the *SCR*-508 series and the *SCR*-509 series, were sets for the Armored Force. The *SCR*-608 and *SCR*-609 series were similar sets later designed for the Field Artillery. The successor to the 609; namely, the 619, which is two-thirds the size and weight of the 609, is going into production to replace the former set.

In the Infantry there was need for quite a different type of set: namely, one weighing only a few pounds that could be used farther forward, even though the communication range might be only a few hundred yards to a half mile. In the fall of 1940 Mr. Mitchell of the Galvin Manufacturing Company came to us with the solution of this problem, and the result was the *SCR*-536, a single-channel crystal-controlled amplitude-modulated set covering the low-frequency band. We had tried many master-oscillator sets of this category, but none was satisfactory, because when you get down to a set of this size there is simply not room to build stability into transmitter and receiver circuits. Mr. Galvin, of course, got the contract for this set and again had to be quite industrious about getting out crystals.

At this time the Infantry division also required a combination vehicular–field set in the frequency band 2.8–6.5. The requirements as given to us by the Chief of Infantry were very severe. One day in early October of 1940 Mr. Clement of the Crosley Corporation came to call on me at the Fort Monmouth Laboratory and stated that his company was considering going into national-defense business and that they were anxious to obtain a development contract for radio equipment. At first I told him that I was sorry that he was too late, that we had 19 radio sets to be developed at once; that we were developing one ourselves and that the other 18 had already been contracted for. At this time we had already endeavored to peddle the *SCR*-284 development to all the radio manufacturers in the country that we could lay our hands on, but none had been willing to undertake it, and I had to give it up as a bad job.

SCR-284 DEVELOPED

Just as Mr. Clement was leaving I remembered our white elephant and called him back and told him that the job was so tough that I did not believe he would be interested, but he undertook the development, and the Crosley Company delivered the first production set in March of 1942, and since that date many thousands of *SCR*-284 sets have been delivered. This set is two packages weighing 35 pounds each, being powered either by battery or hand generator, having both a whip and fixed-length antenna wire, for code and voice transmission.

A lighter-weight successor to the 284, the *SCR*-694, already was on the way soon after the deliveries of the first set. This set was to be moistureproofed and practically indestructible. The 694 was given to Mr. Rauland to produce. Mr. Rauland was assisted in his growing pains by Captain Vanderveer and Captain Ray Morris. It will be noted that we did not use crystal control in this set, but used a crystal calibrator. Without going into the reasons for this, I may state that, although I am an advocate of crystal control, crystal control is not the answer to all problems.

While discussing the radio equipment for an Infantry division I must necessarily now make a diversion to the Cavalry. In the fall of 1940 the Cavalry needed a lightweight radio set that could be carried readily by a trooper and used either on horseback or on the ground. Together with Captain McBride, who was our Cavalry liaison officer, we conceived the idea of building a radio set in the middle of its antenna so to speak. The result was the

Signal Corps photo

Figure 5. A five-man infantry patrol looks for snipers as they move to take the town of Libin in Belgium. Soldier at left carries bazooka in arms; man on far right transmits message to rear with "walkie-talkie" pack radio outfit

SCR-511 in the medium-frequency band. This set is carried by the trooper in exactly the same manner that he carries his guidon; that is to say, the lower end of the antenna is in the stirrup boot. The trooper is provided with a chest set which acts both as a microphone and as a loudspeaker. Again, because of its small size, it was necessary to make this set crystal-controlled, and in this case we provided 20 crystals per set.

Captain James D. O'Connell and Captain McBride always pictured the *SCR*-511 on board a horse. It has been used everywhere but there. Captain McBride did test the set for fragility when rolled on by the horse. He did not, however, test the attempts of the infantrymen to plant the antenna as a flagstaff with one blow of the hand. The Infantry comes into this picture because, when the sets were delivered, higher authority decided that the Infantry divisions needed the sets more than the Cavalry. Consequently, this set has become a standard Infantry-division set, and the Cavalry actually received nothing more than service-test models until after many thousands of sets had been delivered for Infantry-division use.

As I have already stated, there was also a need to replace the *SCR*-195 in the Infantry division, but this proved to be a much tougher problem. The *SCR*-195, though obsolete in principle, had been so well designed and manufactured that we had to wait 2½ years to replace it. Over a period of eight years after the design of the *SCR*-195 we tried forestry sets, Navy sets, sets manufactured for the South American republics, and many others, and tried our own hand at redesigning a set to supersede the *SCR*-195, but were not successful.

FEATURES OF WALKIE-TALKIE

Finally, in 1942 development contracts were given to six different firms, all with slightly different directives, and the *SCR*-300 (the present frequency-modulation walkie talkie) combined the best features of all of them. This set was turned over to Doctor Noble of the Galvin Manufacturing Company to produce. It was waterproofed, fungus-proofed, practically indestructible, and weighed only 32 pounds, complete with battery. The set is not crystal-controlled but has a crystal calibrator and a very effective automatic frequency control in the receiver which enables it to be successfully netted in spite of the lack of crystal control. This was done at the expense of considerably widening the channel spacing as compared with the 508 series of sets, the *SCR*-300 using a channel spacing of 200 kilocycles as compared to 100 kilocycles for the 508 series.

It too had its growing pains in that initially our miniature tubes were not rugged enough for this set. E. W. Ritter, Captain Trenary, and Lieutenant Colonel Maier were a special committee to improve the miniature-tube business rapidly. This was done by interchanging the best factory techniques among the various producers of miniatures. Mr. Ritter contributed immensely in reducing the glass shrinkage by making stress-and-strain studies of the base and the glass involved. Shrinkage was cut from 80 to 10 per cent in the factory and from 40 to 3 per cent in the Government service.

Thus far we have considered only point-to-point radio-communication operation in nets. By reason of rapid movement of a mechanized army, the troop movement would soon outrun the wire system. To handle this situation we have provided a highly mobile long-range radio set in its various forms known as the *SCR*-299, 399, and 499, and we have also provided a radio-relay system. A forerunner of the 299/399/499 series was the *SCR*-299.

In the fall of 1940 we secured a number of models of commercial types of radio transmitters varying in power from 200 to 500 watts and after comprehensive tests selected the Hallicrafter *HT*-4 transmitter as the commercial job best suited for our purpose. Working with the engineers of that company Colonel O'Connell, Captain Soules, and Mr. Jipp of the Signal Corps Laboratories strengthened and modified the *HT*-4 to make it more suitable for military operations and mounted it in a 1½-ton truck together with two superheterodyne receivers of the Signal Corps Laboratories' design, a trailer power unit, and a number of additional accessories.

This set takes care of the situation when the Armored Forces outrun all other types of communication, and in addition it is used as a substitute during initial operations for almost any kind of fixed radio installation that may later be installed. Its popularity and suitability are attested by the fact that in going through any of the theaters of operation one has a feeling that he is surrounded by 299's, 399's, and 499's.

Speaking of our radio program in general, the introduction of frequency modulation in appropriate cases greatly improved communications by minimizing the effect of static and ignition and other vehicular noises. Colonel O'Connell at an early date became convinced of the necessity also of applying radio-suppression measures to all military vehicles, because in a column of trucks interference comes not only from the radio-equipped vehicle itself but also from the vehicles in front and behind and those passing by. Early pioneering assistance in this matter was given us by Ray C. Ellis of Delco and a competent group of Delco engineers. This work was followed up by our establishment of a vehicular radio laboratory in Detroit, and by cooperation with the Ordnance Department and the automobile manufacturers we have been able to establish a complete suppression program.

The radio-relay system originally called the radio-link equipment, was accumulated in the summer of 1941, and that fall a demonstration was given in the North Carolina maneuvers by Major O'Connell, Mr. Marks, Mr. Hessel, and others, to demonstrate the principle of main-axis communication by means of repeaters. This equipment is now known as the *AN/TRC*-1 and is again a frequency-modulated equipment in the high-frequency range of 70–100 megacycles, using beamed antennas. The successors to it for special purposes are underway—the *AN/TRC*-5, 6, and 8, all equipped for carrier operation, both voice and telegraph. In addition, an amplifier has been worked out for the *AN/TRC*-1 to extend its range.

The utility of this type of equipment was not recognized until it was shipped to North Africa in the spring of 1942. Captain Perkins and five engineers from the laboratory did yeoman service in furnishing emergency communication during the Tunisian campaign. During the Sicilian and Italian campaigns, its utility was fully recognized. The original equipment consisted of 50-watt Motorola sets with vertical antennas and was intended only as a single-channel voice-relay system. The *AN/TRC*-1 first was used in quantity in the invasion of Normandy and the current campaign in France. Mr. Waite and Mr. Calagouri of the Camp Coles Signal Laboratory accompanied the equipment and rendered valuable service to the armies in France. It is difficult now to meet the requirements for this type of equipment. It is believed that this type of communication will be normal procedure in the opening phases of any meeting engagement, to be succeeded in the later phases by field wire and then by spiral four.

The integration of wire and radio equipment is becoming closer daily. Unfortunately, whereas the radio industry talks in terms of pounds per watt, the telephone industry is still on the basis of pounds per milliwatt. Rapid strides are being made in the development of a comparable lightweight system by the wire-communication industry. With the full utilization of sound power in voice communication, the radio will be pushed to maintain its lightweight leadership.

DEVELOPMENT ALLIED WITH PRODUCTION

Though I have dealt only with development, development can never be dissociated from production, and in the early days the two went hand in hand. Through the co-operation of our contractors and with the help of the Radio and Radar Division of the War Production Board under the leadership of Ray C. Ellis, Colonel Elder, assisted by Mr. Lack in Army–Navy Electronic Production Agency and the procurement districts under General Farmer, Colonel Daw, and Colonel Corput, managed to boost Signal Corps ground- and air-equipment deliveries from $12,000,000 for December 1941 to $175,000,000 for December 1942, and the $175,000,000 in equipment delivered during December 1942 was modern equipment.

Standards for Steam Turbine Generators

THE JOINT COMMITTEE on Steam Turbine Generators was established by the board of directors of AIEE and council of American Society of Mechanical Engineers to prepare preferred standard ratings and characteristics of steam turbine generators.

The objective of the Joint Committee was the establishment of standard ratings and characteristics of steam-turbine-generator units that would closely fit the requirements of purchasers, the selection of operating pressures and temperatures for each standard unit, and the fixing of standard extraction temperatures for the various units. General acceptance of the standards should result in reduced prices and shorter deliveries than for nonstandard machines and should permit of a decrease in time required by manufacturers to submit performance estimates.

These standards in no way will prevent the purchase of any size of steam turbine generator that is desired for any set of operating conditions different from those indicated in these standards, but such units may not have the benefits expected to accrue through use of the standardized units. Further, the standards are not intended to prevent the purchase of duplicates of machines already installed and for which designs, patterns, and the like, are available.

The preferred standards are intended to be progressive standards and to permit technical and economic development, consistent with the fundamental purpose of expediting production and installation of steam-electric generating equipment. To that end they should be reviewed, at least annually, and as occasion seems clearly to warrant, to determine whether advances in the art call for specific modification. Standardization is not expected to stifle development but, on the other hand, should make available more effort for improvements and research work.

Standardization of steam turbine generators and their extraction conditions should permit, to a degree, similar standardization of steam-producing equipment and accessories, piping, condensers, extraction heaters, make-up evaporators, and so on, all of which should tend to decrease first cost and time required for delivery and installation of equipment.

The initial activities of the Joint Committee have been confined to condensing units for operation at 3,600 rpm, between the ratings of 11,500 kw and 60,000 kw, the former being a logical first step beyond existing National Electrical Manufacturers' Association (NEMA) ratings and the latter representing the rating of tandem-compound machines with double-flow low-pressure elements equipped with largest last-row blades or buckets now available for 3,600-rpm service.

The Joint Committee consulted frequently with technical committees of the AIEE, Association of Edison Illuminating Companies, and Edison Electric Institute. Through these technical committees information has been received from operating companies having more than 18,000,00 kw of steam-turbine-generator capacity installed on their systems. This information has been of great value and has been utilized in the preparation of the standards.

The significant features of the standards shown in the attached tabulation of ratings and characteristics are:

1. Six standard unit ratings from 11,500 kw to 60,000 kw, inclusive.

2. One or two standard values of throttle pressure and temperature for each rating.

3. Definite number of extraction openings for each machine, with specified values of saturation temperature at each opening when operation is at turbine-generator rating with full extraction from all openings.

4. Specification that the guaranteed turbine capability, in kilowatt output at the generator terminals, shall be ten per cent above the turbine-generator rating of each unit, instead of the 25 per-cent margin usually provided in the past.

5. Specification that the power-factor rating of the generators shall be 85 per cent at the generator rating, and yet provide greater kilovolt-ampere capacity in proportion to the capability of the turbine than in present designs; also that the short-circuit ratio of the generators shall be 0.8 at generator rating.

6. The two smaller units will have air-cooled generators, whereas the four larger sizes will have hydrogen-cooled generators, the latter rated for normal operation with 0.5 pound per square inch gauge hydrogen pressure and with 15 per cent additional kilovolt-ampere capability above generator rating provided by increasing the hydrogen pressure to 15 pounds per square inch gauge.

It is recommended that purchasers consider use of these preferred standards in procuring new steam-turbine-generator capacity.

The personnel of AIEE–ASME Joint Committee on Steam Turbine-Generators is as follows:

Representing AIEE. M. S. Oldacre, *chairman;* F. S. Brown, R. P. Crippen, E. S. Fields, H. S. Fitch, J. H. Foote, C. M. Laffoon, J. B. McClure, S. H. Mortensen, Stanley Stokes.

Representing ASME. K. M. Irwin, *chairman;* R. C. Allen, C. B. Campbell, A. G. Christie, G. A. Gaffert, E. H. Krieg, A. L. Penniman, Jr., W. F. Ryan, G. B. Warren.

STANDARD SPECIFICATION DATA FOR GENERATORS

In addition to the afore-mentioned standards for turbine generators, which were prepared by the Joint Committee, standard specification data for generators have been prepared by the AIEE group of the Joint Committee. The data cover detail information that will assist in the standardization of the generators.

The standards and the standard specification data will be available in a short time as regular publications of the societies.

Preferred Standards for Large 3,600-Rpm Three-Phase 60-Cycle Condensing Steam Turbine-Generators

		Air-Cooled Generator		Hydrogen-Cooled Generator						
		Rated for 0.5 Pounds Per Square Inch Gauge Hydrogen Pressure								
1.	Turbine-generator rating—kilowatts	11,500	15,000	20,000	30,000	40,000	60,000			
2.	Turbine capability—kilowatts	12,650	16,500	22,000	33,000	44,000	66,000			
3.	Generator rating									
	Kilovolt-amperes	13,529	17,647	23,529	35,294	47,058	70,588			
	Power factor	0.85	0.85	0.85	0.85	0.85	0.85			
	Short-circuit ratio	0.8	0.8	0.8	0.8	0.8	0.8			
4.	Throttle pressure—pounds per square inch gauge	600	600	850	850	850	or { 1,250	850 }	or { 1,250	950 }
5.	Throttle temperature—degrees Fahrenheit	825	825	900	900	900				
6.	Number of extraction openings	4	4	4	5	5	5			
7.	Saturation temperatures at openings at "turbine-generator rating" with all extraction openings in service—degrees Fahrenheit: 1st	175	175	175	175	175	175			
8.	2d	235	235	235	235	235	235			
9.	3d	285	285	285	285	285	285			
10.	4th	350	350	350	350	350	350			
11.	5th				410	410	410			
12.	Exhaust pressure—inches mercury absolute	1.5	1.5	1.5	1.5	1.5	1.5			
		Operated at 15 Pounds Per Square Inch Gauge Hydrogen Pressure								
13.	Generator capability at 0.85 power factor—kilovolt-amperes			27,058	40,588	54,117	81,176			

A tolerance of plus or minus ten degrees Fahrenheit shall apply to above saturation temperatures. (Tolerances shall be unilateral so as not to reduce the spread in temperature between adjacent extraction openings.)

"Turbine capability" is guaranteed continuous output at generator terminals when the turbine is clean and operating under specified throttle steam pressure and temperature and exhaust pressure, with full extraction from all extraction openings.

Essential substance of "Preferred Standards for Large 3,600-Rpm Three-Phase 60-Cycle Condensing Steam Turbine Generators (Larger Than 10,000-Kw Rated Capacity)." This Standard has been prepared and approved by the Joint Committee on Steam Turbine Generators of AIEE and the American Society of Mechanical Engineers and will be published by the Standards committee at a future date.

Statistical Methods in Quality Control

I. Variability of Quality—Frequency Distributions

This first of a series of articles on statistical methods in quality control, prepared by the AIEE subcommittee on educational activities and sponsored by the AIEE subcommittee on statistical methods, discusses the use of frequency distribution in the regulation and control of variability of quality and the conclusions that may be drawn from it.

THE AIM of the manufacturer of electric apparatus and equipment is to reproduce the same thing again and again. But as in the mechanical and other fields he recognizes that it is quite impossible to make two things exactly alike. Even with the best-known means of regulating raw materials, production machinery, and manual operations, he will find that there are always measurable differences in the individual articles turned out by the production process. Thus one of the basic characteristics of quality—its variability—is something that we never can get away from, but statistical methods can be helpful in regulating and controlling it, from article to article, from machine to machine, from day to day, and so on.

GRID POTENTIAL IN VOLTS		FREQUENCY	FREQ. IN %
−4.7 TO −4.6	II	2	3.3
−4.5 TO −4.4	II	2	3.3
−4.3 TO −4.2	II	2	3.3
−4.1 TO −4.0	卌	5	8.3
−3.9 TO −3.8	III	4	6.7
−3.7 TO −3.6	卌 III	8	13.3
−3.5 TO −3.4	卌 卌 IIII	13	21.8
−3.3 TO −3.2	卌 III	8	13.3
−3.1 TO −3.0	卌 IIII	9	15.0
−2.9 TO −2.8	卌 I	6	10.0
−2.7 TO −2.6	I	1	1.7
	TOTAL	60	100.0

Figure 1. Building up a frequency distribution by classifying the measured values

Suppose we were to take a batch of some 60 power thyratrons and measure the critical grid potential on each of them under a standard test procedure. This group of 60 measurements might look somewhat as shown in Table I. We notice that although we would like to make this critical voltage the same for all of the tubes, the individual values vary from unit to unit. Recognizing that some variability is unavoidable in repetitive manufacture, the designer normally includes in his specifications certain limits within which the critical voltage must fall (−4.8 volts minimum and −2.3 volts maximum in this case) in order that an individual thyratron will be satisfactory for the service for which it is intended.

We can scan this mass of numbers, but we do not get much of a picture of the situation as a whole since there is just too much for the mind to comprehend at a glance. All that needs to be done is to choose, as in Figure 1, some suitable class intervals of equal width and then make a tally in the proper class or "cell" for each of the measured values shown in the table. The result is a *frequency distribution*, the term frequency here denoting *frequency of occurrence*.

From such a distribution, we quickly get a picture of certain features of the group quality of this batch of 60 thyratrons, such as

(*a*). The approximate central value or *average*.

(*b*). The spread or *dispersion* of values.

(*c*). The relation of the quality of the batch as a whole to the specified minimum and maximum limits.

Figure 2 presents this same information in a somewhat more formal manner, together with the results of measurements of specific quality characteristics for various other electrical products. All these diagrams give the same general story, namely, a considerable amount of variation in quality from article to article. All the diagrams show a bunching of values near the middle and a trailing off toward the extremes.

Just what does such a frequency distribution reflect?

First, it provides a condensed description of the group quality of the particular set of *articles tested*. Second, if we also had the qualitative information that this particular set of articles was a sample selected at random from a large production lot, then the frequency distribution provides us with information regarding the quality of the *lot* as a whole, which includes both tested and untested articles. Third, and more important still under these conditions, the distribution provides a quantitative picture of the production *process* itself at the time of manufacture of the particular lot which this sample represents. The variation, for example, in grid potential of the thyratrons tested reflects the many causes

Table I. Measurements of Critical Grid Potential in Volts on 60 Low-Voltage Power Thyratrons

−3.5	−2.6	−4.7	−3.5	−2.9
−3.6	−2.8	−4.2	−3.2	−3.1
−4.0	−3.2	−3.2	−2.8	−2.6
−3.4	−3.8	−3.1	−3.4	−3.7
−3.2	−3.4	−3.0	−3.0	−4.1
−3.5	−3.5	−4.1	−3.1	−2.9
−3.5	−3.9	−4.0	−3.6	−3.1
−3.6	−3.3	−3.2	−3.9	−4.6
−3.4	−3.3	−2.8	−3.6	−2.9
−3.3	−4.5	−3.4	−3.1	−3.1
−3.4	−4.3	−3.4	−3.9	−3.6
−3.0	−4.4	−3.5	−4.1	−3.6

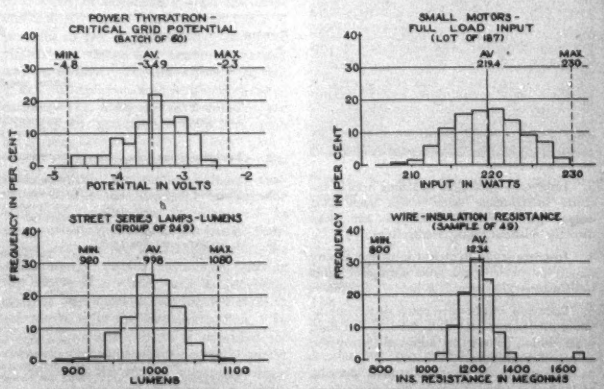

Figure 2. Frequency distributions of individual quality characteristics

Personnel of the AIEE subcommittee on educational activities: J. Manuele, H. F. Dodge, A. I. Peterson, and R. E. Wareham.

of variation in this characteristic contributed by materials, machine operations, and manual operations. If the distribution is poorly located with respect to the specified limits, this then may be taken to indicate the need for some corrective action on the process itself. Fourth, if we knew that this distribution represented measurements made on a whole series of random samples from a series of production lots and that the results of this series of samples had been found to exhibit "statistical control," then this information would allow us to predict within limits what we could expect in future product made by the same controlled process. This is a desired goal for many technical products.

REFERENCES

1. ASTM Manual on Presentation of Data, American Society for Testing Materials, Philadelphia, Pa., 1943.

2. Economic Control of Quality of Manufactured Products, W. A. Shewhart. D. Van Nostrand Company, Inc., New York, N. Y., 1931.

Dual A-C Network Calculator

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A new network calculator with two independent master instrument and control desks affords means of conserving time of operation and obtaining greater accuracy for large complex systems.

STUDIES of electric-power-system expansion and changes for war needs have been speeded up by the use of a new network calculator. This new calculator is twice as effective as previous ones, because the simultaneous solution of two independent networks is possible for large complex systems involving high-voltage trunk lines and low-voltage networks which if put on a common base would handicap accuracy of readings because of extreme wide limits of power quantities. By means of two instrument desks and suitable selector switches for the various component elements of the calculator, the large complex system can be broken up into two independent systems as may be found desirable.

The enlarged and improved calculator is a product of knowledge acquired from more than 500 system studies on earlier designs and experience gained in the construction of calculators for public utilities and other concerns operating extensive electric networks. This new calculator provides improved mechanical and electrical features which result in increased speed of operation, higher accuracy, and greater convenience to the user than previous designs. The outstanding improvements are:

1. Two instrument desks which permit simultaneous working of two problems.

2. Increased number and range of circuits which represent the corresponding parts of an actual system.

3. Improved metering facilities which include instruments with scales such that actual power-system quantities are read directly without using multipliers.

4. Instantaneous electrical selection of any circuit for metering purposes with pilot lights indicating which circuit is being metered.

5. Location within easy reach of the operator of all devices such as generator and load units, which have to be adjusted during the course of a problem.

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Every element in a power system has its counterpart on the network calculator. In addition to portraying electrically such concrete objects as a 100,000-kw generator or a 200-mile transmission line, network-calculator circuits can represent such abstract concepts as the zero-sequence mutual inductance between a pair of feeder circuits. The number, type, and range of the various circuits is indicated in Table I.

With this number and range of adjustable values, the calculator can represent power systems varying in size from that of the modern airplane network to the largest system interconnection covering many states. At one time a resistor–reactor element may represent only 100 feet of cable and yet at another time be used to reproduce a 100-mile section of line.

A general view showing ten of the 17 steel cabinets and one of the two instrument and control desks is shown in Figure 1. Right behind the meter-desk operator are located the 18 generator units with their associated voltmeters, ammeters, wattmeters, and controls. Voltage and phase-angle control of the generator units are independent of one another. Voltage adjustment corresponds to excitation changes in the actual system and phase-shifter adjustment corresponds to changes in the governor setting of the actual system. The generator internal impedances are low-loss reactors with a sufficient range to represent subtransient or synchronous reactance of the generators.

Table I

Number	Type	Purpose	Range	Steps
18	Generator units	To represent generators or phase-shifting transformers	0–440 volts	Smooth
			0–360 degree angle	Smooth
18	Generator reactance unit	To represent generator reactance	0–499 ohms	0.2
152	Line-impedance units	To represent line impedance and transformer reactance	0–399 ohms resistance	0.2
			0–301 ohms reactance	Smooth
48	Load-impedance units	To represent shunt loads	0–3990 ohms resistance	2
			0–2400 ohms reactance	Smooth
48	Load-adjustor units	To maintain constant load	±10 per cent	1 per cent
48	Capacitor units	To represent line-charging-capacity synchronous condensers, negative reactance	0–4.1 microfarads	0.01
36	Autotransformer units	To represent transformer taps	±10 per cent	1 per cent
36	1/1-ratio two-winding transformers	(a). To permit representing mutual induction between parallel circuits when connected as 1/1 ratio, or (b). To permit using two or more kilovolt-ampere bases simultaneously for extended range problems when connected as a 2/1 autotransformer between parts of the complete network		
48	Meter jumper circuits	For bus connection and totalized metering		

Figure 1. General view of calculator room showing steel cabinets containing circuit elements, control desk, and work table (in foreground)

The load circuits are equipped with means for connecting the resistance and reactance elements either in series or in parallel, so that with the same resistance and reactance circuit a range of loads of 100 to 1 can be represented. The load adjusters are autotransformers permanently connected in series with the load units. With these units the power and reactive kilovolt-amperes drawn by a load unit can be maintained at a constant value even though voltage on the load unit may vary over a wide range during a series of studies.

The condenser circuits are adjustable over a sufficiently wide range so that one circuit element can represent the line-charging capacity of the smallest line section or a large synchronous condenser. The autotransformers can represent regulating transformers as well as the main transformer tap of power transformers.

The combination 1/1-ratio two-winding or 2/1 autotransformers are new units which have been added to the calculator and replace the older 1/1-ratio transformers formerly used only to assist in representing mutual induction between parallel circuits. When connected as 2/1 autotransformers they permit using two kilovolt-ampere bases for a single network that is not too involved and yet needs one base for high-voltage high-power circuits and a lower base for low-voltage lower-power portions of a combined system. This is an intermediate step to separating the network into two independent systems and operating the two master instrument desks simultaneously. The characteristics of the particular system determine which method is better suited. When the 2-to-1 transformers are used, the high-voltage system is operated at twice the voltage of the low-voltage system, and, consequently, lower impedances and higher currents can be used on the low-voltage part of the network, thus extending the range of readable values.

All circuit elements are mounted in drawers which can be withdrawn readily to facilitate inspection (Figure 2).

The calculator circuits can be connected to either instrument desk by an instantaneous circuit selector controlled from a 26-button keyboard mounted on each instrument desk. By pushing three keys the desired circuit is immediately connected to the instruments. Two independent sets of instruments are provided on each instrument desk so that the actual system quantities can be obtained in the most directly useful terms applying to the specific study. Direct readings in calculator quantities can be obtained in volts, amperes, watts, vars, and phase angle. The voltages and currents can be metered in scalar values, vectors, or as components with respect to any selected reference. Losses can be obtained directly. For most voltage-regulation studies the scalar voltages and the power and reactive kilovolt-amperes are the most useful quantities. In this case only two instruments are used, the voltmeter and a combination watt-var meter which gives these readings direct. Reading of actual system values has been achieved by equipping the instrument with a scale selector which permits choice of a scale in accordance with the kilovolt-ampere base. With system bases of per cent or per unit on 10,000, 20,000 or 40,000 kva the actual system quantities can be obtained directly without the use of any multipliers except setting of decimal points. The numbers on the scales are changed in accordance with the base being used.

The physical arrangement of the new calculator and the mechanical and electrical details are designed to provide maximum production as measured in terms of calculator data per hour. Individual circuits are so arranged that the units which require adjustment during the course of a study, such as generator units or load circuits, are located close to the operator at the instrument desk. In addition, remote control is provided for the generator units which normally would be used with the second instrument desk. An independent set of generator instruments is mounted on this second desk, and with this remote control the operator has complete observation and means of adjustment of the units directly from the instrument desk. This remote control consists of key operation of small reversing gear motors connected to the generator-unit voltage regulators and phase shifter. One key provides for raising and lowering the voltage and another key for changing the phase shifter clockwise or counterclockwise.

All these new features have simplified the procedure in making studies. Certain time-consuming steps such as the conversion of network-calculator readings to actual system quantities have been eliminated. The steps to be followed with the new calculator are:

1. Assemble and arrange impedance and other data of the power system, preferably in the form of single-line diagram.
2. Convert these data to a common base, such as per cent on 10,000 kva, 20,000 kva, 40,000 kva, or decimal multipliers thereof.
3. Set up the network and adjust the loads and the generator inputs in accordance with the requirements of the specific problem.
4. Meter the network and record directly on the one-line diagram the significant calculator readings such as voltage, watts, and vars.
5. Analyze the results, and determine the best plans for solution of the problem.

In addition to the new electrical and mechanical features of the calculator,

Figure 2. Draw-out-type circuits are readily accessible for inspection and maintenance

improved technique in operation and in presentation of results has been developed. The time required for the various steps in a solution has been reduced to a minimum. The efforts of the engineers conducting the study therefore can be utilized almost entirely in an analysis of results and planning the procedure to be followed for subsequent studies.

Grounding Principles and Practice

V—Static Electricity in Industry

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INDUSTRY and the war effort are paying a large toll to static electricity in the cost of work stoppage and slowdowns, in the cost of property damage from fires and explosions, and most unfortunate of all, in the cost of injuries to personnel and in the sacrifice of human lives. The disturbing note in this situation of industrial sabotage lies not so much in the lurking evils of the cause itself as in the casual attitude with which industrial management, in general, seems to countenance these hazardous and costly nuisances.

The "mysterious" behavior and the destructive propensities of static electricity, under various circumstances, are fairly well known to those who have devoted years of specialized study to learning the characteristics of electrification and to devising tailor-made methods for its control. It is unfortunate for the initiate that he must discover for himself the large crop of confused, contradictory, and erroneous statements that lie buried in the literature of the subject. The many and glaring violations of electrophysical principles that have accumulated in the written word of this particular subject are probably the result of too much theoretical speculation and too little experimental evidence and practical knowledge.

Industry is finding itself confronted with a "two-barreled" program in combating the ravages of electrostatic sabotage. First the problems within the plants must be carefully segregated and analyzed, and then corrective techniques must be devised for and applied to each elemental problem, individually. Obviously experience and ingenuity are the investigator's chief assets in these experimental studies. The degree of success attained in an applied solution can be determined only by quantitative data as obtained from the application of proper instrumentation in testing. Secondly, and quite as important as the first, a comprehensive training program should be organized and administered by which the operating personnel is made alert to the nature of the electrostatic problems, to their particular hazards, and to the observance of every tenet in carefully prepared codes of maintenance and safety practices.

All of these schedules are the responsibility of management—first of having the electrostatic problems solved in the most capable manner possible, and secondly of seeing to it that they stay solved, by enlisting the co-operation of an effectively trained operating personnel.

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The hazards of fire and explosion are ever present in many industrial processes, awaiting only a spark to bring disaster—and static electricity can and often does provide the spark. The limitations of grounding as a universal remedy and the need for expert analysis of the problem are emphasized in this article, which is the last of five based on a series of lectures on the subject which was sponsored by the power and industrial group of the AIEE New York Section during the 1943–44 season.

IS GROUNDING THE PANACEA TO ALL ELECTROSTATIC PROBLEMS?

If the answer to the query were in the affirmative, all electrostatic ills could be readily cured by simply grounding the component parts of the offending machines or devices. Let us examine the general problems of how electrostatic hazards arise, and then deduce an appropriate reply to this question.

HOW ELECTRIFICATION ARISES

Electric charges, which always occur in pairs of positive and negative kinds, are brought into being when any two dissimilar substances are in contact. The negative charges—the electrons—migrate to one substance and their positive counterparts, in equal numbers, remain on the other substance. The number of charges thus developed in the substances depends upon the nature of the substances, the extent of area in actual contact, the temperature, the cleanliness of their contacting surfaces, and the pressure between them. In order to become aware of the presence of these charges, the substances are most commonly separated, and this process generally is referred to as generating static electrification. For the generation of an appreciable, or readily measurable, amount of electricity by such separation, at least one of the substances must be practically nonconductive. In this instance the charges become entrapped and impounded, during the process of their separation, upon the substances to which they became attached while the two substances were in contact.

The nature of the contact between the two component substances in most industrial operations is influenced by physical pressure, either with or without accompanying friction. The pressure may be light, as when paper or textile stocks travel over idler rolls; or the pressure may be great, as it is between the embossing rolls for imprinting wall paper, or as exists at the treads of automobile tires; or the pressure may be the result of zephyr-like contacts of finely dispersed powders such as sulphur, flour, and many others which are air-borne during transportation through parts of the manufacturing processes.

If one of the separating components, such as a machine part, is conductive, it should be grounded permanently in order to discharge itself continuously during its operation. Conversely, the nonconductive substance, that is, the product, retains its impounded charges, and when the electrified product becomes separated by its movement from the grounded machine part—as two charged plates of a capacitor might be moved farther apart—the voltage between them increases, enormously at first and about in proportion with the distance of their separation. But as the distance of separation becomes appreciable, the increase in voltage grows less and less, until finally further separation causes no additional voltage. Interestingly enough though, when two substances are firmly pressed together, they are still no nearer to each other than the dimensions of an atom—this being a separation of about 10^{-8} centimeter.

CONTACT DIFFERENCE OF POTENTIAL

At this inconceivable closeness of atomic dimensions, the electric forces within and between the atoms at the contiguous surfaces of both substances undergo such modifications and reorientation that boundary electrons are caused to pass from the surface atoms of one substance into those of the other. In this way the one substance becomes negatively charged, while the other substance by losing electrons acquires an equal positive charge. The principle that underlies this little-known process is the contact difference of potential theory.

Investigations into this realm of theory have divulged some valuable and basic information on the subject of contact electrification. When a poorly conducting liquid makes contact with solid insulators or with metals or with other liquids, or when two solids are pressed into contact, that substance becomes positively charged which possesses the higher dielectric constant. The term "dielectric constant" in being variously defined also has been described simply as expressing the ease of displacing an electron within an insulator. The potential difference between, or its equivalent, the charge per unit of contact area of any two such substances in contact is proportional to the difference of the two dielectric constants.

The dielectric constant for para rubber, for example, ranges around two to three, depending upon its inherent composition, while for glass it ranges from about four to nine. Because of their high conductivities, metals have long been considered to have dielectric constants of infinitely large values, but more recently their values have been ascribed to an order of three to four as a result of the definite positions which metals take in the contact-potential series that embrace a wide scope, and a large number, of substances. Hence ordinary rubber would acquire negative electrification in contact with most metals or with glass, although for glass, because of its larger value of dielectric constant, the magnitude of the charge would be proportionately greater than for metals.

If two substances of crystalline structure which possess perfectly flat, or so-called optically flat, ground surfaces are placed in contact, their contact electrification, thus acquired, is entirely independent of the physical pressure between them. Since the surfaces of materials which form contact by pairs in industrial processing are relatively rough and uneven, in comparison to optically flat surfaces, their contact electrifications are found to increase with incremental pressures up to a characteristic maximum, or saturation, value for the two substances. This maximum charge is attained when every microscopic unit area of one surface is in complete contact with corresponding unit areas of the other, as would readily obtain, without appreciable pressure, if the two substances formed perfectly flat surface contact. If an amorphous substance, of which rubber is an example, forms a perfectly flat contact with another substance, unlike crystalline materials, the resulting contact electrification increases with pressure until a maximum charge is attained, after which the charge remains independent of additional pressure.

In particular, where one of the substances is fibrous such as a textile, the process of rubbing the substances together causes many more parts to form momentary contacts than would stationary pressure alone, so that in this manner more electrons may pass from one substance to the other and thus augment the charges on each of them. Although this process of electrification by rubbing one substance against the other is often called "frictional electricity," actually the basic process of generation here is still the application of the contact-difference-of-potential theory.

The rubbing of a vulcanite rod with a piece of flannel or fur is an example of this so-called frictional effect in creating electrification. Although the difference of potential between the opposite charges on the two contacting substances may be only a very small fraction of a volt, perhaps of the order of millivolts, yet upon an appreciable separation of the two members, the voltage may increase thousands or even millions of times, thereby causing the ultrahigh potential differences which are so frequently observed in many industrial processes. As is well known, the electrification produced on a vulcanite rod by rubbing it with fur may remain there for hours when the air is dry, even though one end is held in the hand or connected by a wire to ground. If the vulcanite were a perfect insulator, the electric charges could remain impounded on its surface indefinitely, but because no substance is a perfect insulator, the electric charges at one area gradually diffuse over the entire surface of the substance. Under this condition, if a conductive path were provided, the charges would flow to ground.

From this explanation the answer should be clear to the query "is grounding the panacea to all electrostatic problems?" Under certain conditions, grounding will effectively discharge electrified conductors instantly; but obviously, charged insulators are not affected by grounding, except over long periods of time. Other methods of neutralization than grounding must be applied in the case of insulators; unfortunately, it is on substances of this kind, which are the most common types of products in many manufacturing operations, that the most troublesome problems of electrification occur.

HUMIDIFICATION AS A GROUNDING TECHNIQUE

It was mentioned earlier that, provided the ambient air was dry, electric charges generated at one end of a vulcanite rod would remain there for hours even while the other end was grounded. It should be clearly understood that this statement does not imply that, conversely, if the relative humidity is high, the electric charges drain off directly into the humid atmosphere. Moisture in the air in vapor form, as available data substantiate, is much too tenuous to provide this direct means of dissipating the charges, and in fact, water vapor in the atmosphere has been found to be practically a perfect insulator unless the strength of an applied electric field exceeds a certain critical value. Except for a few unusual materials, of which ceresin wax is a notable example, most substances possess hygroscopic properties, by which physical behavior water vapor from humid atmospheres may condense upon surfaces under certain conditions, and in so doing may render them partially conductive.

In this manner, if conditions are favorable, humidification causes more or less imperfect grounding. The surface film of moisture reduces the surface resistivity, while the volumetric resistivity depends upon the degree of absorption of the substance. The conductivity of the moisture is greatly affected by its ion content, and this is affected largely by the solubility of surface impurities or by the surface molecules of the substances, particularly where acid or alkaline solutions are formed. If on the other hand, substances are maintained at a temperature above that at which surface films of moisture can form, because of the processes of evaporation, then the surface cannot become conductive even though the relative humidity be high.

The humidity, when formed by fine spray, as from spray-type humidifiers or from steam jets, can lead to electrification under some conditions rather than to its mitigation. In the spray mists at the foot of water falls, it has been found[1] that below diameters of 80 angstroms, the water particles are always found negatively charged, while for diameters between 80 and 150 angstroms the vapor particles are always positively electrified. For vapor particles larger than 150 angstroms, no electrification is found. (One angstrom equals 10^{-8} centimeter.)

In this connection, the condition should be mentioned that, with hygroscopic materials in the presence of high-humidity atmosphere, even the generation of appreciable electrification is not favored because the two substances behave as conductors, even though both may be nonconductors. In other words, while the two component substances are pressed firmly together or rubbed tightly against each other, positive charges on one and negative charges on the other are actually produced; but in the act of separating the component materials, the charges reunite and leave little or no resultant electrification in evidence.

On the converse, in the absence of practically any surface moisture, such as for values of humidity of the order of one to five per cent, the author has found a marked reduction in the degree of possible electrification. Under this condition, electrons can only pass from one substance to the other at the microscopic high points which form contacts between the two. In the presence of a slight amount of surface moisture, as when humidities of from 10 to 25 per cent are prevalent, the microscopic contacting points may be considered as being broadened into greater areas of contact, as well as the number of contacts being considerably augmented. Both of these conditions favor the passage of more electrons from one substance to the other. Since the amount of moisture on the surfaces in contact is still too small to render

them even appreciably conductive, the electrons become entrapped upon one of the substances when separation of the two surfaces occurs. For a given set of physical conditions, an optimum value of electrification may be determined for a given value of relative humidity.

The change in leakage resistivity with humidity for various natural and synthetic waxes and for bakelite[2] is shown in Figure 1, wherein ceresin wax is seen to be notably superior, and in fact almost perfect, as a nonhygroscopic insulator.

If electrification by friction is possible, and the two members are charged as a result of favorable low humidity, grounding of the insulated substance does not result in its immediate discharge. If the other substance is conductive, and its charges are not bound to it by the attractive electric forces from the charges of the insulated member, grounding is effective here in completing its discharge. Actually though, if the separated members are in close proximity, the positive charges on the one do remain bound to the negative charges on the other by virtue of the electric field between them, even though one should be grounded. If both members are grounded, and both are conductors, the opposite charges would then flow together, as a conductive interconnection is provided between them. Should one of these interconnected members be an insulator, the high resistance of it would prevent its electric charges from neutralizing those on the other, except as neutralization would occur by the slow process of gradual leakage of the charges through the imperfect insulation.

Should electric charges be continuously developed and should they be generated more rapidly than they can neutralize each other by the process of leakage, then the voltage between the two generating substances would continue to rise until a certain saturation level is approached. This saturation level of voltage between the charging members is influenced by two electrical properties; one is the gradual decrease of electron flow from one substance to the other through their contacting surfaces because of the increasing repulsion to their flow by the accumulating negative charges on the negative substance; and the other property is that, beyond a definite critical amount, or density, of charge on the two substances, the voltage which is developed between them, as the substances separate, causes the initiation of a "corona" within the intervening atmosphere whereby the otherwise almost perfect insulation of the ambient air is made semiconductive by the production of ions and the charges on the two substances become partly neutralized in this manner.

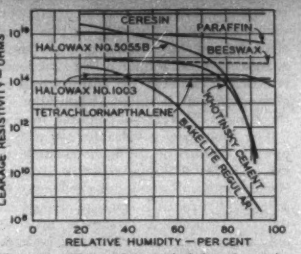

Figure 1. The surface resistivity of certain waxes is seen to be independent of relative humidity, whereas for most of the otherwise excellent insulators, as for bakelite, their resistivities vary greatly throughout the humidity scale

PROPERTIES OF CAPACITORS

When two charged conductive members are in proximity and insulated from each other, the pair constitutes a capacitor. Capacitors are not always so geometrically formed as one finds them in the laboratory or in a radio set. As an illustration in practice, consider where one member, or plate, may be the ground and the other a metal roof of highly irregular form, which is supported and insulated from ground by a wood-framed structure. The capability of a capacitor to store electricity, called its capacitance, is expressed by either of two basic and well-known definitions: one in terms of the physical factors, $C = KA/t$; and the other in terms of the electrical factors, $C = Q/V$. Another important relationship which is basic to electrostatic problems is obtained by equating these two expressions and solving for the difference of potential, giving $V = Qt/KA$. In these expressions the symbols have the following significance:

C = capacitance in farads
A = active area in square centimeters, where active area is that area of the dielectric between the plates which is under stress of the electric field
t = thickness in centimeters of the dielectric between the plates
K = dielectric constant
Q = electric charge in coulombs
V = potential difference in volts between the plates

The electric energy which is stored in a capacitor is vitally important in electrostatic problems, as it determines the intensity of the spark and the potentialities for ignition from a spark which occurs between the plates. The expression for the electric energy stored in a capacitor is

Energy $E = {}^1/_2 CV^2$ joules, or watt-seconds

As an illustration of the application of this sparking energy in fire or explosion hazards from volatile flammables, consider some of the common hydrocarbon fuels which, when admixed in vapor form with air at atmospheric pressure, range within the combustible limits of approximately 1.2 per cent and 8.0 per cent by volume. Some of these can be ignited by an electric spark whose threshold energy is as low as 0.0005 to about 0.001 joule. Characteristic curves[3] are shown in Figure 2 for minimum ignition energies in terms of fuel–air mixtures for benzene and for natural gas under conditions of different sized electrodes and gap lengths. The increase in the threshold values of the ignition energy, as shown here, which results from the cooling effect of larger electrodes at a given gap length for benzene, or of shorter gap lengths for a given electrode size for natural gas, are strikingly illustrated in this figure. The influence of gap length on minimum ignition energy for electrodes of one size—${}^1/_2$-inch-sphere electrodes—is illustrated in Figure 3 for natural gas. The threshold ignition energy approaches its minimum value for spark gaps somewhat longer than 0.10 inch, while for spark gaps under 0.05 inch the ignition energy is seen to increase greatly. A person whose capacitance to ground is, say, 100 micromicrofarads, that is, 10^{-10} farad, if charged to 10,000 volts from scuffing on a rug, can provide a spark energy upon discharge of 0.005 joule, or roughly ten times the minimum energy necessary to ignite a flammable mixture of benzene vapor and air.

The plates of a charged capacitor may be connected together by a wire, in which case the plates would be discharged instantly. If, on the other hand, the wire had a resistance R of very high value, the flow of electrons from one plate to the other, which causes the discharge, would be greatly retarded, so that several seconds, minutes, or even hours would be required for completing the discharge. The time in seconds for full discharge to take place is about three times the time constant, where the time constant is equal to the product of the capacitance C in farads of the capacitor and the resistance R in ohms of the discharge path. The expression for the time constant T is

$T = CR$ seconds

and for the time t in seconds for the full discharge of a capacitor, the expression is closely

$t = 3CR$ seconds

Inasmuch as the term "time constant" is employed so frequently in considerations relative to electrification, the meaning of the term is clarified still further by showing it graphically on a charge and discharge curve for a capacitor. As Figure 4 shows, a capacitor charges to 63 per cent of its ultimate value during the period of the time constant; and on discharge, it loses 63 per cent of its charge during the same period of the time constant.

As an illustration of the application of the time constant, consider the time required for a tank truck of 1,000 micromicrofarad capacitance to discharge through its tires to a grounded steel grating on a bridge, where the resistance of the

tires in parallel to ground is, say, 10^9 ohms. The time constant $T = 1{,}000 \times 10^{-12} \times 10^9 = 1$ second, and the time for complete discharge is closely $t = 3T = 3$ seconds. If the charged truck came to a stop on a dry concrete highway, where the resistance from the tires to ground through the concrete is, say, 10^{12} ohms, the time for complete discharge would be 1,000 times greater, or 50 minutes.

If a piece of fabric in a processing machine of some kind is electrified, by reason of its charge it constitutes the equivalent of one plate of a capacitor and the ground, most probably, being the other plate. If a wire connects one point on the charged fabric with ground, the time of discharge, here too, depends upon the time constant of the discharge circuit. In this instance, because of the varying lengths of flow paths to the wire, the resistance varies widely for the flow of the charges through the high resistance of the fabric.

GROUNDING FROM NATURE'S STATIC—LIGHTNING

A charged cloud, say of negative electrification, is known to form strong electrostatic attraction with equal numbers of positive charges in every intervening structure on the earth's surface below, be it a steel-framed building or tower, or a tree, or a rubber-tired tank truck. These positive charges have been formed by the process of electrostatic induction from the cloud, whereby the negative charges of the cloud repel electrons from atoms or molecular groups in those structures within the influence of the intervening electric field. As the electrons evacuate their neutralizing positions in the atoms and molecules, positively charged ions remain which are bound electrostatically to an equal number of negative ions in the cloud. If electrification of the cloud increases, other factors remaining constant, the increasing voltage between the cloud and earth may cause the ionizing potential gradient of the air to be exceeded wherever sharp edges and points exist and thereby greatly multiply the number of air-borne ions. Since these ions cause a neutralization of some of the positive and negative charges at the earth's structures and the cloud, and thus reduce the voltage between the cloud and earth, the probability of a lightning stroke is appreciably lowered.

This corona effect is the principle upon which the use of the lightning rod is predicated. By employing sharp-pronged aerial terminals on lightning rods which project well above the structure to be protected, the density of the charge at the sharp tips, or in other words the electrostatic field intensity or the voltage gradient, is enormously increased. In this manner, the critical voltage gradient causing corona discharge is reached at the sharp points at a much lower cloud-to-earth voltage than would otherwise occur. Hence, the striking voltage may be held somewhat in check, tending to diminish the likelihood of a direct lightning stroke; but in the event of a stroke actually occurring, it is more apt to impinge upon the lightning rods than elsewhere, because the conductive ionized paths in the air, along which the stroke travels, emanate from the "corona points" on the rods. If the lightning rods, their interconnecting leads to ground, and the grounding electrodes are all properly installed, the lightning stroke passes harmlessly through the conductors into ground, or vice versa.

If the ground resistance is high, say 100 ohms, then as little as 10,000 amperes through it would cause a potential difference across it of 1,000,000 volts. This high voltage could very well lead to side flashes through part of a building or elsewhere from which attendant hazards or damage could result. The current in some lightning strokes is well over 100,000 amperes, and the need for low-resistance grounds is even the more apparent. In other words, terminal ground resistance for lightning protectors should be maintained as low as feasible, of the order of one ohm or less if possible, and the grounding plates, where used, should be buried to a depth of at least ten feet. By so doing, the paths of flow of current from the buried electrode into the surrounding earth are so deep that the probability of dangerous potential gradients existing on the surface of the ground above is much less than for a shallow buried electrode. Voltage gradients at the surface of the ground, which are produced in this manner, account largely for the frequent electrocutions of cattle from direct lightning strokes to trees, as they gather under trees for protection from storms.

If the rate at which the charges are generated on the cloud exceeds the rate of the neutralization of charges by the discharging process of corona, eventually such a high voltage is attained that the intervening air between the cloud and earth becomes sufficiently conductive along ionized streamer routes to permit the initiation of a mighty spark—a lightning stroke—which in a few millionths of a second discharges the cloud, or a certain portion of it. At the earth's surface the lightning stroke generally impinges upon the tallest conductive structure which is beneath it, such as a tall steel building; but the current in the stroke, which may be many thousands of amperes, causes no harm provided the electrical resistance at the foundations of the building to ground is negligibly small. Such a tall conductive structure normally provides a "cone of protection" against lightning strokes to nearby structures of lesser heights, if the latter are contained well within the bounding surface of an imaginary cone as formed from the apex of the tall building to a symmetrically centered base at the ground plane which has a circle roughly equal in radius to at least twice the height of the building.

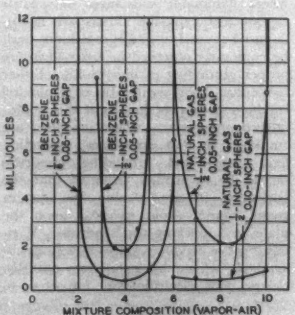
MILLIJOULES
BENZENE ½-INCH SPHERES 0.025-INCH GAP
BENZENE ½-INCH SPHERES 0.05-INCH GAP
NATURAL GAS ½-INCH SPHERES 0.05-INCH GAP
NATURAL GAS ½-INCH SPHERES 0.10-INCH GAP
MIXTURE COMPOSITION (VAPOR-AIR)
—PER CENT BY VOLUME

Figure 2. Minimum electrostatic ignition energies for benzene and natural gas are shown as functions of fuel-air mixture, electrode size, and spark-gap length

Predicated on this hypothesis, the lightning protection of critical areas has been provided by the erection of one or more tall steel towers on properties which house munitions manufacture and storage, large oil reservoirs, gasoline tank farms, and other locations where costly damages could result from fires and explosions if they were permitted to be initiated by uncontrolled lightning strokes. Where a number of towers are erected for this purpose, more effective protection is afforded by the stringing of barbed wires from top to top of the structures. In all such grounded structures, charges of opposite polarity to those on the overhead cloud are induced and they are held there bound only so long as the overhead cloud remains charged. If a cloud-to-cloud lightning stroke discharges the cloud, the charges on the structures are no longer bound, and they neutralize themselves harmlessly by combining with the opposite charges from the earth.

A cause for many "mysterious" fires, however, has arisen from a somewhat different condition wherein an insulated conductive member, forming a plate of a capacitor, such as an ungrounded metal roof supported on a wood structure or a tank truck standing in a concrete-paved loading yard, becomes charged from a passing cloud by electrostatic induction over a very considerable period of time. Because of the imperfect high-resistance insulation intermediate between such structures and the ground, electric charges are induced slowly into these partially insulated members, slowly because of their large time constants. If the inducing cloud floats away or becomes suddenly discharged, the charges of opposite polarity which were slowly induced upon the structure are no longer electrostatically bound, and thus they remain impounded there as a result of the high resistance to ground. Now a high voltage exists between the electrified structure and ground which is an unsuspected but potential

source of fire hazard. All that is needed to initiate a fire or explosion, resulting from such a charged structure, is the synchronized occurrence of a flammable mixture of fuel vapor and air and a spark of sufficient energy to cause its ignition.

Here is an instance where grounding, if applied to these otherwise insulated structures, would eliminate these potential fire hazards. In other words, in localities where flammable fuel–air mixtures may cause hazardous atmospheres, extra precautions should be taken to insure thorough bonding and grounding of all isolated metal parts of structures and of large metal surfaces throughout the dangerous zone.

CHARGING OF INDIVIDUALS

The experience of discharging long sparks from one's finger tips to a radiator, gas stove, or elevator after walking on carpets or rugs within doors during the cold, dry, winter weather is frequently amusing, but the experience, if permitted under certain other conditions, may be surcharged with grave consequences. Explosions have originated in this manner in hospital operating and treatment rooms from anesthetic vapor and air mixtures which have resulted in serious injuries or deaths to patients, to surgeons, and to attendants, as well as in demolition of buildings. Certain industrial processes in ordnance plants, for example, are so susceptible to explosion hazards from body electrification as to make necessary the exclusion from employment of certain individuals whose abnormally dry skin is found, by test, to cause them to retain electric charges more persistently than others. This physiological condition of dry skin can be corrected by administering certain types of diet and proper vitamins.

An instance is known to the author where a person became so electrified by walking a short distance upon a dry concrete driveway during a cold dry fall day as to have caused the ignition of the hydrogen gas escaping from the storage battery of his recently parked automobile following his removal of the fill caps preliminary to refilling the cells with distilled water. This explosion caused serious injury to his eyes—the loss of sight in one eye, and only by repeated operations was the sight restored to the other eye.

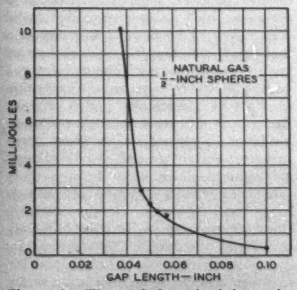

Figure 3. The variation of minimum ignition energy with spark-gap length is seen to be highly critical for short gaps and practically constant for the relatively longer gaps

The accumulation of electric charges on a person's body is affected materially by the high-resistance characteristics of the shoes and socks which he wears and of the surfaces upon which he walks. Carpets and rugs, with their deep nap, are particularly conducive to the generation of high electrification. To a lesser extent than woolen floor coverings, but still seriously offending sources are linoleum or rubber floor coverings, granolithic and concrete floors, synthetic floor compounds, such as plasticized compositions, waxed surfaces, and certain types of floor paints, especially those employing a titanium-oxide base. Of footgear, the worst offenders are shoes possessing crepe-rubber soles, natural-, reclaimed-, or synthetic-rubber soles, rubber inner soles, or leather sole construction employing liberal amounts of cement or glue compounds, or rubber overshoes or rubber boots.

By way of illustrating the effect of the resistance of footwear, assume the resistance to ground through both shoes to be 1,000 megohms, or 10^9 ohms, and assume the person's capacitance to ground to be 100 micromicrofarads, or 10^{-10} farad, then the time constant, being the product of the two quantities, is 0.1 second. If the resistance of his shoes to ground were ten times higher, or 10,000 megohms, the time constant would, even then, be only 1.0 second. Hence a person would ordinarily discharge quickly to ground if, in his walking, he should tread on well grounded flooring, provided he does not wear rubber footgear. While they are dry, even silk or woolen hosiery can provide the same high-resistance effects as rubber soles.

When operators must work in zones where flammable substances or volatile liquids and explosive vapors are manufactured or used, utmost precautions must be constantly observed in order to insure proper grounding of individuals. Either the entire floor should be of grounded conductive construction, or if this is considered unnecessary, where machines are employed in unit operations, grounding foot plates and grounding handrails should be so artfully installed that the operators, in approaching the danger zones, cannot avoid treading upon the plates and touching the handrails. Various types of conductive floor coverings are available which, by grounding, can discharge any electrification imparted to them.

A number of manufacturers are producing conductive shoes, and although they may not possess really low resistances from body to ground, it is not generally necessary that they should. This can be demonstrated by the following example. In walking rapidly at the rate of four miles per hour, a person takes about two steps per second. Hence, if his electric time constant is of the order of 0.1 second, corresponding to 1,000 megohms for the resistance of his footgear to ground and a capacitance of 100 micromicrofarads, his body would fully discharge during each step. In other words, under these conditions the person could accumulate no appreciable charge.

The greatest offenders in creating "unfriendly" sparks in hazardous zones are visiting executives and employees from other departments of the plant. These visitors are not as well trained to safety consciousness as those who regularly work in the dangerous locations and as those who, perhaps, have seen a fellow worker injured or killed from the result of a momentary relaxation of a safety measure.

POWER AND CONVEYOR BELTS

The annual cost of fire and explosion losses in the industries of the United States caused by electrostatic ignition from power and conveyor belts is estimated at about $4,000,000. These losses occur throughout a wide variety of industries, such as in those using belts to drive machinery in locations where flammable vapor–air mixtures are a potential fire hazard, and in those where power and conveyor belts are utilized in cereal, sugar, starch, and flour mills, in grain elevators and threshing machines, and in sulphur and other dispersion processing. In these industries the dusts constitute finely dispersed fuels of a highly explosive nature, requiring only a properly timed spark and dust–air mixture to cause a catastrophe.

Sparks of four-foot length, estimated in the order of 1,000,000 volts, have been observed occasionally from wide high-speed power belts under favorable conditions. Elihu Thompson reported such observations. Spark discharges from belts ranging from 60,000 to 100,000 volts are more commonly encountered in industrial plants. The charges which are generated on the surface of the belt as it makes tight contact with the pulley face are trapped there by the high resistance of the belt as it separates from the pulley. Each electrified unit area of the belt as it leaves the pulley, because of its capacitor effect, develops a high voltage which attains its maximum value some four or five inches after its separation from the pulley. The slipping of belts has been found to have little, if any, effect in augmenting the electric charge generated by its normal operation. Pulleys should possess conductive properties, as otherwise considerably higher voltages can be generated on the belts.

The pulley and its associated machine rotor should be meticulously grounded in order to permit the continuous electric discharge of the rotating system. If this provision is not made, then the oil films

of the bearings virtually insulate the rotor from the grounded frame of the machine, and depending upon the purity of the lubricating oil, the voltage of the rotor above ground may attain values of 3,000 to 5,000 volts, or higher. In case the belted machine should be a dynamo, the insulation on the rotor windings may become prematurely weakened to the rupturing point by the continual attack upon it of the corona effect of the spurious electrostatic field. The grounding of the rotor may be achieved by mounting a grounded brush firmly against the shaft.

The primary hazard of the electrification of the belt really lies in the magnitude of the stored charge and in its consequent high voltage, and because of this, in its potentiality for sparking. If the belt was composed of conductive material, then no appreciable voltage would result in its operation with a conductive pulley, as each unit area of the belt would continuously and harmlessly discharge at the instant of its separation from the pulley. Just prior to the outbreak of the war, conductive belting was beginning to make its appearance on the market. The use of such belting in conjunction with conductive pulleys constitutes an ideal solution to electrostatic problems of this particular nature.

If the belt is nonconductive, as it generally is, the electric charges may be dissipated by treating the belt with special dressings to provide hygroscopic and otherwise conductive surfaces. Most of these dressings which employ the use of fish oils, glycerine, carbon black, and other hygroscopic or conductive elements require replacement every week or two, and hence the maintenance expense is appreciable. Engineers of the United States Department of Agriculture have developed belt dressings for rubber and leather belts which last for six months or more per application and have been found quite satisfactory.

THE PAPER AND TEXTILE INDUSTRIES

Aside from such special processes as the carding of staples and the production of yarns and threads in the textile field, a number of the processes in the manufacture of paper and textiles have similar problems of electrification. In fact some of these problems are akin to those of power and conveyor belts. The similarity with belt operation is apparent where the paper or textiles flow continuously, frequently at high speeds, unwinding from one roll and rewinding on another, traveling over idler rolls, through driers of various types, through printing machines, and perhaps into cutters. Both paper and textiles are more susceptible to electrification in running over and through systems of rollers than are either rubber or leather belts. There are two basic reasons for this:

1. The resistivities of paper and textiles are, in general, considerably higher than belting so that they retain their charges in greater proportions.

2. Unit areas of the porous paper and cloth fabrics permit much of their inner structures to press and twist into contact with the processing rolls and thus to become charged to greater density by friction effect than would be true if they had a firm, hard structure like that of belting.

Just as for belting, the paper and textiles, as they leave the rollers from which they are charged by contact difference of potential, develop high voltages to ground. But unlike belting, the paper or textile stocks obviously cannot be made conductive by applications of dressings in order to ground the static charges. The presence of high-voltage electrification creates a variety of annoying and hazardous conditions. Machine operators are always confronted with the specter of gruesome personal injuries from being caught in gearing, rollers, belting, and rotating machines resulting from sudden uncontrolled movements which are caused by surprise shocks from the high static voltage. Women operators, by relaxing safety regulations, have suffered most serious accidents by having their electrified hair drawn into gearing, belting, or processing equipment.

In some instances, sparks have defaced high-quality paper, or caused fires by igniting fine lint which gathers on and around certain textile equipment. Where printing of paper or textiles is in progress, fire and explosion hazards are always present as a result of the flammable nature of the volatile solvents in the printing ink. This condition is particularly aggravated in the case of multicolored printing in which the inks possess especially volatile solvents for quick drying in high-speed printing, as in rotogravure service, and in wallpaper and wall-cloth manufacture. As a result of electrification some operations are slowed down appreciably, while others are caused to stop repeatedly because of clogging of machines by the stock. This occurs especially in the folding and stacking of paper, ginning of cotton, and carding of staples. Voltages are especially high on paper and textile fabrics in those operations where high pressures are exerted between processing rolls, such as in calendering and embossing of paper or in calendering processed cloth, and because of this, the hazards of electrification are intensified and multiplied.

The rolls, cutters, printers, and various metal parts of the manufacturing and processing machines for both paper and textiles can, and should be, grounded thoroughly, using grounding brushes on rotating shafts of rollers, idlers, and parts which may otherwise be insulated from machine frames by the oil films within the bearings. Obviously the grounding does not eliminate the static charges, as these are entrapped on the high-resistance paper or cloth fabrics, but grounding does keep the machine parts at ground potential, and hence it controls the magnitude of the voltage to ground by not permitting an accumulative voltage rise.

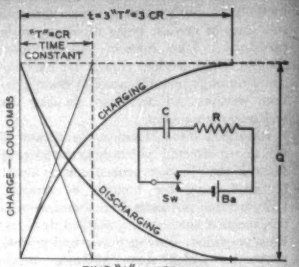

Figure 4. The time constant for the electric circuit shown depends upon the values of C and R_ρ and it is the same for either charging or discharging

In those operations where sparking constituted hazards to safe operation, the electrification of the moving paper and textiles sometimes has been discharged by providing tinsel bars at strategic locations across the width of the moving paper. Here the strings of tinsel were supported by a grounded bar; and, by lightly touching the stock, they were supposed partially to discharge it. Or in place of this method, the stock may be lightly touched by dangling pieces of fine chain which are attached to and supported by a grounded metallic bar. These and other such methods have been employed to a limited degree in the paper and textile industries for decades, despite the added maintenance costs that are necessitated by their upkeep and replacement. The electrostatic problems in modernized paper and textile operations have been aggravated and intensified by the higher electrification resulting from the increased speeds of manufacture, of printing, and of the many attendant processes.

Where fire or explosion hazards, as from the vapor–air mixtures of flammable liquids or gases, are not present, the electrification of belts, paper, and textiles can sometimes be economically and satisfactorily reduced to safe values by the use of static combs. A static comb is placed close to and across the path of the moving stock. It is constructed with an insulating member secured to the supporting ground rod, and the insulating guard is so provided with holes that the corona points projecting from the ground rod lie centered within the holes and the corona points are depressed below the exposed surface of the insulating guard so that the points cannot touch or mar the surface of the stock. Static combs can reduce the voltage to about 10,000 volts, and with modified construction to considerably lower values. This order of voltage, under gas-free or explosive-vapor-free conditions, is not hazardous. The author has used this

method to advantage in the economic solutions of certain types of electrostatic problems. Like doctors' prescriptions, though, these devices cannot be used indiscriminately in the control of electrification without, on occasions, leading to serious consequences.

Localized humidification, by means of wet steam directed by jets onto the moving stock, is used in some processes as an agent for dissipating the charges to ground. Only certain processes lend themselves to this method since the humidified surfaces, thus provided, may acquire undesirable properties which may influence subsequent operations or the quality of the finished product. The steam should be critically controlled, when this method is employed, so as to avoid overhumidification or the dripping of steam condensate. On the other hand, dry, rather than wet, steam independently may contribute, under some conditions, its own generation of electrification. Humidification has been employed extensively over many years in certain processes of the textile industry for the control of static electricity, and to a lesser extent it has been used in the paper industry.

In the cotton industry, static electricity has been a troublesome factor from the beginning of the machine processing. In carding and drawing operations, for example, static electricity causes fibers to fly apart and, hence, to weaken the yarn. An illustration of the electric repulsion of fibers in yarn is shown in Figure 5. Exposure of the fibers to a 50 per cent to 55 per cent relative humidity during these processes has been found to control the electrification fairly well, but if the humidity is increased a few per cent higher, the cotton may then clog on the carding units. Under these conditions, the cotton sometimes catches on fire because of intense frictional heating.

The addition of moisture to the cotton yarns to the extent of eight per cent is stated to increase the tensile strength 30 per cent above what it would be at four per cent moisture. This moisture conditioning of the yarn is believed to improve the subsequent operations of cotton spinning and weaving. The effect of a change in relative humidity from 44 per cent to 82 per cent was found to increase the tensile strength[4] of cotton fabric 14 per cent and linen fabric 21.3 per cent, and to decrease the tensile strength of woolen fabric 14 per cent. Humidities may be maintained in cotton spinning rooms around 55 per cent to 60 per cent while in cotton weaving 80 per cent to 85 per cent are sometimes employed. In general, throughout the cotton industry, the range of 50 per cent to 55 per cent relative humidity is considered beneficial, chiefly so as a means of providing a regain of moisture to the cotton fiber for increasing its strength during processing. Coincidentally, humidification of this range, if properly applied, seems also to provide an adequate lowering of electric resistance within the product for the grounding of electric charges.

PETROLEUM INDUSTRY

The flow of hydrocarbon liquids, as well as other flammable and volatile fluids, through pipe and hose lines may develop very considerable volumetric electrification[5] by the principle of contact difference of potential. Since the resistivities of hydrocarbon liquids are very high, ranging from 10^{13} to 10^{15} ohms per cubic centimeter, the electric charges do not move readily through the fluid under their own interelectrical forces. Strangely enough, too, these fluids do not readily electrify when pure, but the presence of small amounts of impurities, such as free or combined water, tetraethyl lead, entrained air, or metallic oxides is found to accentuate the generation of electric charges. Measurements have shown that the generation of electricity in the flow of gasoline through pipe lines and conventional fill hoses increases about linearly with the rate of flow. On the average, this rate of flow of the electric charges in gasoline has been found to be approximately 3×10^{-10} ampere per gallon per minute.

If gasoline, in flowing through a pipe line at the rate of 100 gallons per minute, discharges into an insulated tank for a period of five minutes, the quantity of electricity stored in the tank at the end of five minutes is

$$\text{Quantity } Q = 3\times10^{-10}\times100\times5\times60 = 9\times10^{-6} \text{ coulomb}$$

Assume the insulated gasoline tank has a capacitance of 450 micromicrofarads, that is, 4.5×10^{-10} farad, then the voltage developed between the tank and ground is

$$V = \frac{Q \text{ (coulomb)}}{C \text{ (farad)}} = \frac{9\times10^{-6}}{4.5\times10^{-10}} = 2\times10^{4} = 20{,}000 \text{ volts}$$

Should this high voltage cause a spark to jump between tank and ground, the energy in the spark would be

$$E = {}^1/_2CV^2 = {}^1/_2\times4.5\times10^{-10}\times(2\times10^4)^2 = 2.25\times10^{-10}\times4\times10^8 = 90\times10^{-3} \text{ joule}$$

This spark energy is seen to be 90 times the conservative threshold energy of about 10^{-3} joule as required to ignite a flammable mixture of gasoline vapor and air.

If the tank in the foregoing example had been grounded, as all storage tanks always should be, the charges in the liquid for a small tank could not accumulate and thus they could not develop the high voltage as shown. On the converse, if the pipe line in this illustration which supplied gasoline to the tank had been insulated, an equal quantity of electricity, but of opposite polarity, would have accumulated on it. Obviously, pipe lines also should be grounded thoroughly.

Hose lines have so-called static wires enmeshed in the rubber which bond their brass connectors at each end and thus a tank truck is presumed to be grounded when the hose is connected to it, provided the discharge end of the hose is grounded by contact with the fill pipe of the storage tank. In cases of ordinary loose nozzles being placed in fill pipes, this may not be true, and hence a serious ignition hazard can exist at the opening of the fill pipe where flammable vapor–air mixtures are most likely to be present. The screw-in discharge nozzle, of the type required in the City of New York,[6] assures reliable grounding of the truck to the tank and also precludes the escape of explosive vapor–air mixtures at the fill pipe. A tank truck should be electrically discharged before its hose connections are made by attaching a permanently connected reel-in grounding cable from the truck to a suitable grounding clip on the vent pipe or other part of the storage tank.

The rain discharge of petroleum, and other flammable products, from an overhead orifice into a tank aggravates the problem of electrification and of fire hazards. The breaking up into drops of the inflow stream of the product between the end of the discharge orifice and the surface of the liquid in a tank, especially in large field storage tanks, may be, in some instances, a further source of electrification—a phenomenon akin to that by which clouds become electrified through the breaking apart of water droplets. Sparks as much as four feet in length have been reported as occurring from the surface of oil to the sides of the tank where cylinder oil was being discharged from an overhead orifice into a large steel storage tank.

The petroleum or other products should be introduced into the storage tank near the bottom, using discharge fittings so arranged at the side of the tank as to direct the electrified fluid against the grounded metal. Violent agitation of the liquid within storage tanks should be avoided, especially where it disturbs the water bottoms in the tanks or where it allows air to discharge up through the liquid, as these conditions may also generate hazardous

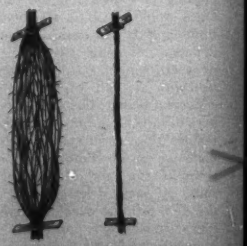

Figure 5. Cotton, wool, or synthetic staple yarns, when electrified, balloon during their spinning operations as shown on the left, and the repelled and loosened fibers weaken the strength and lower the quality of the yarns

electrification. This difficulty is unavoidably encountered in tank agitators for the purification of kerosene and other petroleum products at refineries; and unless special methods of mitigation of electrification are applied here, fire and explosion hazards are constant threats to plant safety.

Field storage tanks of a wide variety of constructions which range in sizes up to 150 feet in diameter are found in service. Experience seems to indicate that the all-steel type of tank, with floating roof structure, is particularly free from hazards of fire and explosion possibilities. With this type of roof structure, little or no gas storage space is provided above the product. Obviously too much attention cannot be directed toward providing and maintaining tight valves, leakproof fittings and manholes, and properly installed vacuum-pressure vent systems. Steel tanks constitute their own safe lightning protection, just so long as no gas leaks are permitted and adequate ground conduction is provided. Wood-roof tanks and reservoirs have the least degree of safety from lightning hazards.

Throughout the petroleum and other industries in which highly flammable volatile products are manufactured, transported, and utilized, fire and explosion hazards abound on all sides. Generally speaking, these electrostatic hazards are recognized only vaguely by the operators within these industries, but in order to prevent fires and explosions, the instruction of operating personnel in safety methods must be given constant attention. This is particularly so whenever any deviations from standard procedures of handling the products become necessary, either as temporary expedients or as permanent practices.

RUBBER-TIRED VEHICLES

This subject has been presented by the author in a number of periodicals,[7] and hence, only the importance of grounding will be treated here. In transit on the highways, at high speeds, tank trucks may develop 15,000 to 25,000 volts, or more, to ground during favorable weather for electrification. Also, in discharging loads of flammable products, several thousand volts may be developed. For this reason, utmost care should be exercised for the safe handling of all flammable, volatile, products.

The tank trucks should be promptly grounded upon arriving at their destination, that is, at the loading racks of bulk supply stations, and at service stations. They should be maintained at ground potential during all of their immobile periods in order to avoid hazardous electrifications by extraneous electric induction. In being parked on concrete and other ultra-high-resistance pavements, for which the charging time constant may be large, the electrification of a tank truck to high voltage by induction may occur very slowly; but also because of this large time constant, the vehicle when so electrified may retain its unbound charge for an equally long period of time. In the interim, the vehicle presents unsuspected electrostatic hazards which may lead to a fire or an explosion. An example was cited earlier in the article to emphasize this hazard.

The perennial question as to the effectiveness of drag chains for discharging rubber-tired vehicles has been settled experimentally by the author, to his own satisfaction, as having no practical value; and, in fact, in some instances, drag chains have been known to introduce additional hazards by virtue of the mechanical sparks which they create. If perchance the drag chain could discharge the vehicle, because of a low-resistance roadway, then the truck body would readily discharge itself anyway through its tires, upon stopping, in the short period of two or three seconds.

Also, attention should be called to a fallacy, which unfortunately is receiving considerable publicity, to the effect that the use of conductive rubber tires would constitute the perfect solution to this problem of electrification of rubber-tired vehicles. If the electric resistance of the highway from the tire treads to ground were of a relatively low order, this statement would be quite true; but in this instance the statement also would hold true even with the use of conventional tires. The fallacy in the statement lies largely in the misconceived value of the electric resistance of the highways. A dry concrete or asphalt highway has a surface resistance and resistance to ground which may be several orders higher[8] than the resistance of the conventional rubber tire from wheel rim to the tread. For this reason the highway would retain its generated electric charges which are produced at the tire treads, and the conductive rubber tires would retain theirs of opposite kind because they could not escape.

In this connection, though, it should be pointed out that, by employing the proper mixture of ingredients in the manufacture of rubber for tires, it may be entirely possible to compound the rubber composition so as to give a low contact difference of potential between the tire treads and the concrete of the highway. If this refinement in tire construction were made, little if any voltage would be developed on the car body while the vehicle was operating on that particular type of concrete highway. However, contamination of dirt on the surface of the concrete roadway, or changes in the ingredients or mixture of the concrete from place to place, would largely counteract the advantage of the special tire composition. Then, too, a tire which was compounded to provide negligible contact voltage with concrete might generate an exceptionally high voltage with asphalt, brick, macadam, or other common forms of roadway surfaces.

Table I. Record of Dust Explosions in the United States*

To September 1, 1942

Classification	Total Explosions	Explosions With Injury or Fatality	Number Killed	Number Injured	Number Explosions With Reported Losses	Amount of Losses
Grain elevators	150	59	115	281	138	$24,531,218
Woodworking plants	100	42	30	132	73	2,713,613
Feed and cereal mills	90	37	63	222	79	7,351,510
Flour mills	87	25	28	46	62	4,548,300
Starch and corn products	38	18	128	130	32	5,384,824
Cork dust	37	7	6	28	34	181,190
Pulverized coal	26	14	21	26	24	92,359
Sugar refineries	25	4	12	31	14	1,622,300
Fertilizer plants	26	5	7	20	14	852,450
Malt houses	23	2	2	18	18	747,500
Metal dusts	36	21	49	76	32	1,684,163
Sulphur dusts	23	7	2	39	15	80,095
Bark dust	14	1	0	2	13	587,600
Coffee and spice dusts	11	2	5	13	9	201,700
Cotton mills	13	4	2	4	8	78,950
Paper dust	7	0	0	0	7	395,000
Phonograph-record dust	6	1	0	1	5	56,400
Pitch and resin dust	15	7	14	57	12	2,098,472
Rubber dust	7	3	11	2	6	30,300
Miscellaneous	46	20	24	78	38	2,510,992
Totals	780	279	519	1,206	633	$55,728,940

* National Fire Codes for the prevention of dust explosions—1943, National Fire Protection Association.

DISPERSION INDUSTRIES—EXPLOSIVE DUSTS

In those industrial processes devoted to reducing a vast variety of substances to powdered or granulated form, many of these powders become highly electrified and some are violently explosive. In order to convey some conception of the seriousness of dust explosions in the United States, data from the National Fire Protection Association are presented as Table I.

In addition to the statistical information in this table, it serves to list by industries the origin of many of the dusts that are sources of particular hazards. Only a small proportion of the explosions which have been recorded in the table was allocated definitely to electrostatic origin, although many of those reported as "cause unknown" might well have been from this source. Of all the explosions listed, those occurring in grain elevators are seen to lead in number and in amount

of loss, although woodworking plants, feed and cereal mills, flour mills, starch and corn products, sugar refineries, and metal dusts are also serious offenders.

Electrification in many of these industries occurs by crushing, pulverizing, and grinding processes. The products are commonly conveyed from process to process and to storage by conveyor belts, by belt-type bucket elevators, by screw conveyors, by revolving metal screens, or through airblown channels. Their collection for temporary storage is commonly accomplished by dumping into bins through chutes, or by using cyclone, bag, or screen-cloth collectors. All of these methods are conducive to generating extraordinarily high electrification. All metal parts within the danger zone of the plant should be thoroughly bonded and grounded, belts should be made conductive, buckets attached to belts should be interbonded, and bag or screen-cloth collectors should be interwoven with copper wires and grounded. Compressed air never should be used for cleaning by the method of blowing dust about, as in this way the dust may attain its maximum electrification, and some dust clouds, notably sugar dust, may self-ignite from the miniature lightning flashes thus produced within them. Vacuum cleaning is the safest procedure, and meticulous housekeeping throughout the danger zone is of paramount importance.

Humidification, as a mitigating agency for electrification in many of these dispersion processes, may not be permitted because of the deleterious effects upon hygroscopic powders and upon various moisture-susceptible products under manufacture. If humidity control can be applied without harm to the products, it may be as helpful here, depending upon conditions, as in other industries. The introduction of certain highly flammable dry powders into mixers, or the processing of powders in grinders, in attrition mills, or in ball, roll, or hammer mills, may constitute a very hazardous operation. Grounding of all metal parts is essential; but, in addition, other means or modifications in processing may be necessary to control effectively the electrification.

While conducting investigations relative to fire and explosion hazards from electrostatic causes in certain industries, the author has experienced several occasions during which his quantitative findings have lead either

1. To the recommended introduction of more desirable alternate plant processes by which the resulting electrification was reduced to nil.

or

2. To basic changes in certain plant operations whereby substantial annual economies were realized—in addition to providing entirely satisfactory solutions to the electrostatic problems.

GASES AND VAPORS

Gases and vapors, when not contaminated with impurities of foreign solid or liquid particles, have been found to generate little, if any, electrification in their flow. Generally, such a pure condition of gases does not exist, because metallic oxides from the scale of pipes through which the gases flow, or water vapor, or other such contaminants, are commonly present.

Steam in flowing from a nozzle or from a leaky pipe creates particularly high electrification. For example, steam at a pressure of 75 pounds per square inch issuing from a $^1/_{16}$-inch hole and impinging upon a parked tank truck a few feet away was found to develop a voltage of 20,000 volts between the tank and ground in five seconds. This corresponds to an approximate rate of flow of electricity of four microamperes. The grounding of pipe lines and of miscellaneous metallic parts, where fire or explosion hazards are possible, should be carefully performed and thereafter maintained. If the tank truck in the above illustration had been grounded, no electric charges could have accumulated on it.

Compressed air, like steam, also can impart high electrification, when it impinges upon insulated objects. The air, under high pressure, contains particles of condensed water vapor which adds materially to the magnitude of the electrification that is generated. The nozzle or orifice, if insulated, acquires electric charges of one kind, while the projected particles and the air stream possess charges of the opposite kind.

Hydrogen is probably the most hazardous of all gases, as its explosive range with air extends from 4.1 to 74 per cent by volume, and also it is susceptible of ignition by a spark energy of as little as 2×10^{-6} joule. In the pure state, no electric charges are generated by the flow of hydrogen. But as it is commercially handled in industry, such as flowing through pipe lines, discharging through valves at filling racks into pressure containers, or flowing out of containers through nozzles, the hydrogen is found to contain particles of oxides carried off from the inside of the pipes or containers. In this contaminated state, it is highly susceptible to electrification and it constitutes a most dangerous product, requiring utmost care and constant vigilance for safe handling in its manufacture, transportation, and use. If by faulty generation, some oxygen is contained with the hydrogen in the tanks, a violently explosive condition exists. The author investigated an explosion from just such a cause which demolished the service building, damaged others, and resulted in injuries and deaths to workmen.

The spraying of paints and lacquers by aspirating and atomizing them with high-pressure air may generate electrification of dangerous magnitude under certain conditions. The solvents in fast-drying lacquers are highly volatile and flammable, and explosions may be caused from electrostatic sparks where spraying is conducted under improper conditions. Thorough ventilation should be provided and all metal objects within the room should be grounded, and especially the objects being sprayed. Obviously no smoking or flames of any type should be permitted within the danger zone.

Carbon dioxide in being discharged from orifices under high pressure, for industrial purposes, can cause high electrification of the containers. The condition here is not unlike the effects from contaminated compressed air or from steam flow, although the change in state, in addition to the contact effects at the orifice, is believed to play a contributory part in the process of electrification.

HOSPITAL AND TREATMENT ROOMS

Unfortunately, the anesthetics which are applied to patients in hospital operating rooms and in certain treatment rooms are basically highly explosive. Utmost precautions should be demanded by the administrators of hospitals and especially observed by anesthetists. The inane argument has been advanced that the casualty of some 25 patients per year in a rough approximation of 1,000,000 anesthetized admissions to hospitals per year in the United States is too small for alarm. But this argument cannot condone the abuse of the Hypocratic oath of the medical profession in failing to observe

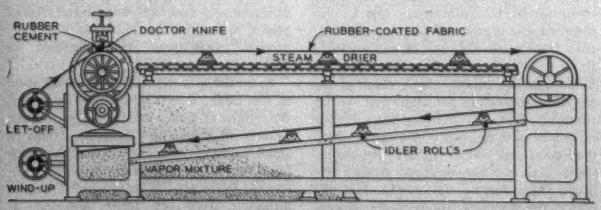

Figure 6. This typical rubber-spreading machine shows the indicated accumulation of flammable solvent vapor on the floor where it creates serious fire hazards in proximity to the dried and highly electrified coated fabric in its return passage over the idler rolls to the windup reel

every possible and known means of preserving human life. Surgeons, doctors, and operating personnel should be educated to understand fully the hazards to life in using the highly volatile and violently explosive anesthetics which are entrusted to their administrations.

Methods have been devised whereby the application of anesthetic vapors can be confined wholly to the patient by the total-rebreathing technique. These methods of total-rebreathing techniques should be developed to the eventual exclusion of the older methods. Utmost care, even in the approved techniques, must be observed constantly in order to insure against the production of hazardous electrostatic sparks by the flow of the gases through the controlling orifices.

In operating rooms, the sources of electrostatic sparks arise chiefly from the manipulations of the operating-room attendants. Scuffing over and walking upon insulated floor coverings during favorable weather for electrification generate high voltages on the bodies of the surgeons and the attending personnel. The slipping of rubberized and conventional sheeting from operating tables is especially conducive to generating electric sparks. Also, the friction of clothing of nurses may cause dangerous sparks. All of these conditions which are hazards of the medical profession should be known to all surgeons, to nurses, and to hospital attendants; and the explosion and fire hazards, together with their mitigating procedures, should be taught through courses of instruction to all who engage in operating-room services. The precautions against the hazards of explosion to be observed by the personnel in operating-room practices, and the methods of mitigating the electrification in these hazardous services, have been developed and publicized sufficiently to leave no excuse for ignorance or for negligence in their observance either by those performing within the dangerous zones or by the administrative staffs who are responsible for hospital equipment and techniques.

The means for reducing to a minimum fire and explosion hazards which originate from electrostatic causes are

1. In using the closed system of applying the anesthetics, thereby preventing the diffusion into the room of the highly explosive vapors.

2. In employing a conductive type of flooring or floor covering which should be permanently grounded.

3. In the mandatory use of a conductive type of footgear on every person engaged in operating-room service.

4. In utilizing only conductive coverings, sheetings, and other materials on operating tables.

5. In having the metal operating tables grounded to the conductive flooring by the use of conductive rubber casters or of multiple short drag chains.

6. In having nurses use conductive clothing throughout so that generated charges are dissipated to ground as rapidly as they are produced.

7. In providing explosionproof electric switches, outlets, lamps, and so forth, and grounded electric parts throughout the operating room.

THE RUBBER INDUSTRY

Various rubber-manufacturing processes in years prior to the present war were sources of high electrification, but the high voltages presented, for the most part, only the minor problems of disagreeable shocks to the operators, rather than of causing serious fire and explosion hazards in plant operations. The advent of synthetic-rubber manufacture during the present war period has caused new techniques to be developed in the processing of rubber products utilizing synthetic rubber largely of the buna and butyl series. Since the rubber industry now embraces the manufacture of the synthetic rubber, as well as its fabrication into the multitude of products, the problems of electrification and the resulting hazards of fires and explosions have been enormously multiplied in each of these two major divisions of industrial operations.

The manufacture of synthetic rubber is essentially a chemical process, in which the fundamental raw materials, whether they be of the petroleum family or of the alcohol group, are converted into intermediate components which are highly volatile and flammable, such components being ethylene, vinyl chloride, vinyl acetate, ethyl benzene, butadiene, styrene, isoprene, and the many others. These constituent products because of their insulating properties are in themselves, or in combination with other substances, highly susceptible to electrification; and through their vaporous states, they are readily ignited even from relatively feeble electric sparks. In attempting to control the electrification, the grounding of mixers, stills, and other chemical apparatus is essential, and the dissipation of the electric charges should be achieved in whatever ways are most readily adaptable to the processes. In addition to the conventional methods of controlling the electrification, the use of inert ambient atmospheres as a dilutant for escaping flammable vapors, such as encasing the pipe lines which carry highly flammable liquids or vapors within inert gas-filled outer pipes, may offer mitigating possibilities and safety practices not as yet utilized to advantage.

Where synthetic rubbers are employed in the fabrication of automotive tires, airplane and tank parts, and rubber-cement compounds, to mention only a few processes, the volatile vapors that are gradually given off from the entrained solvents within the synthetic rubber, or from the solvents which are directly applied in the processing, constitute potential sources of fires and explosions from electrostatic sparks. The solvents commonly employed in treating the synthetic rubbers are gasoline, benzene, naphtha, toluene, xylene, acetone and carbon disulphide, all of which are highly volatile and readily flammable—a hazardous condition that is especially marked in the case of carbon disulphide, with its low boiling temperature of 114 degrees Fahrenheit, since it has an explosive range from 1 to 50 per cent by volume with air.

In addition to thorough grounding of all processing-machine parts, including calender rolls, idler rolls, Banbury mixing paddles, and innumerable moving parts, the generated electric charges will require control by other methods. Humidification has been found by the author to augment electrification in certain processes of high-temperature drying, and thus, it has its limitations as a mitigating agent, here, as in other industries. Where the rubber is calendered onto cotton or rayon fabric, the adhesive properties between the rubber and the fabric are weakened by humidity of sufficient magnitude to mitigate the electrification. In some of the manufacturing stages, the processed rubberized stock is so highly heated that moisture, even from an excessively humid atmosphere, cannot condense upon its surface and thereby lower its surface and volumetric resistivities.

The conduction of charges to ground from inherently insulated products may be accomplished in certain favorable operations by applying lightly contacting conductive brushes. Where particularly perverse cases of otherwise-unmitigated electrification arise, ionizing units of one kind or another may be employed to advantage. In the operation of these units, the air is ionized by collision into positively charged molecules and into electrons within the immediate vicinity of the electrified product. The desired reduction in electrification of the processed material results from the electric charges on the product attracting the oppositely charged ions of the air.

Thorough bonding and grounding of the parts of the machines are of primary importance as a first step in the procedure of controlling the electrification. If fabric stock is running through a machine slowly, while it is being humidified by wet steam, say from steam jets, the charges may be enabled to dissipate themselves to the rolls and, through them, to ground. The author has measured voltages of 15,000 to 80,000 volts from the stock to ground under many conditions, such as in the rewinding of rolls of cotton cloth, in the calendering of rubber stock, in the embossing of wallpaper, or in the drying of rubber-proofed cloth.

In this latter case several fires occurred daily in rubber-cement spreading machines of the type shown in Figure 6. The volatile vapors of the solvents in the synthetic rubber cements, such as toluol, zylene, naphtha, gasoline, benzene and other

hydrocarbons, ether, and alcohol solvents, all being heavier than air, settled downward to the floor under and around the spreader. The proofed fabrics, after running over idler rolls above the drying coils to the windup roll, become charged to high voltage. Naturally any intense electric sparks occurring here cause fires to be originated. Antistatic generation was found an effective means of electrostatic control in this process, although its maintenance and supervision required frequent attention. By this method, the idler rolls of the spreading machine were covered with a fabric of the type which was found to generate practically zero contact potential with the rubber-coated stock. Later these machines were enclosed in solvent-recovery units whereby the solvent-vapor–air mixtures were attenuated well below the flammable ranges of the solvents. In this way the elimination of the fire hazards from electrification occurred as a by-product of the operation of the solvent-recovery system—thereby solving both problems simultaneously.

SUMMARY ON GROUNDING

The foregoing characteristics of electrostatic behavior in the few typical industrial processes which were cited, and there are others too numerous to mention, can well serve as a basis for formulating certain conclusions regarding the effectiveness of grounding as a means of mitigating static electricity.

1. All stationary parts of machinery which are employed in processes where static electricity is generated should be permanently grounded, not only to provide safety to operators, but also to prevent differences of potential to grounded members or to other machines.

2. Rotating parts of such machinery should also be grounded, using a suitable form of grounding brush to bear on the rotor or shaft, as otherwise a difference of potential of several thousand volts may exist between the rotating and stationary parts of the machine. In addition to the fire hazards from such sparking, the lubricating properties of the oil in the bearings may be gradually destroyed by the production of acids which occurs from their chemical reaction with the ozone from electrostatic corona and sparks. In some cases where sparks have struck through the oil films of bearings of ungrounded rotors, the bearing surfaces have been prematurely deteriorated by roughening.

3. Where explosive atmospheres pervade wooden buildings or lurk around out-of-doors structures or equipment, all metal parts such as metal roofs, tanks, wire fences, railway sidings, bodies of rubber-tired vehicles, and the many others should be grounded in order to discharge, harmlessly, whatever electrification was produced originally by induction but which later became released as unbound electricity by the dissipation of the inducing charge.

4. Grounding wires should be so installed as to be protected adequately against inadvertent breaking, or otherwise a most effective spark gap may be unsuspectingly established between the concealed ends of the broken wire, and thus, a particularly hazardous situation may obtain when grounding discharges occur.

5. Where electrostatic generation is produced on rapidly moving stocks of the types that are inherent insulators, such as paper, textiles, power and conveyor belts, and rubberized fabrics, all grounded objects which are near such electrically charged products provide sparking hazards; if possible, such grounded objects should be removed to safe distances in order to prevent inadvertent jumping of sparks.

6. Obviously the sparking hazards incidental to the electric charges that are developed on rapidly moving stocks, as enumerated previously, cannot be removed by the grounding of idler rolls, calender drums, and other processing parts of the machines, but the grounding of the machine parts plays an important role in limiting the otherwise sporadic rises of potential above that of ground where recommended grounding practice is not observed.

7. The temporary grounding of portable equipment during certain operations in the presence of flammable ambient atmospheres may constitute a highly dangerous practice, unless approved grounding methods are employed. Such hazards of fires and explosions are peculiarly characteristic to those operations in which small quantities of solvent liquids are employed in mixing rubber cements and printing inks, in operating extractor units in certain chemical operations, and the like, where solvents are bucketed from one location to another. Here floors, personnel, machines, and buckets should be scrupulously maintained at ground potential at all times, as safety measures in avoiding the insidious occurrence of sparks, fires, and explosions.

DANGER IN UNFOUNDED REMEDIES

In conclusion, the author, as a safety engineer, would be negligently remiss in his obligations to industrial management and to plant engineers by omitting to call their attention to the dangers and fallacies which can be concealed in the ill-advised practice of applying cure-alls for the elimination of electrostatic ills within their plant processes.

These very people would abhor vehemently the wily suggestion of employing a proprietary "quack curative" for treating their personal ills, and they would be wise indeed to renunciate as vigorously the use of inexperienced initiates in trying to apply palliatives to their industrial electrostatic hazards—potential dangers as they are which may lead to damage or destruction of physical plant, to injuries or even deaths of personnel, to loss of community good will, and to costly sabotage of industrial operations.

The solutions to such problems of fire and explosion hazards arising from the electrostatic ills of the industrial plants are developed and evolved as the culmination of a systematic program of diagnoses of the conditions, of quantitative investigations of all the pertinent physical factors, and of specialized applications of mitigating devices and techniques.

REFERENCES

1. Properties of Ordinary Water—Substance (book), **N. E. Dorsey**, physicist, National Bureau of Standards. Reinhold Publishing Company.

2. Influence of Humidity Upon the Resistivity of Solid Dielectrics and Upon the Dissipation of Static Electricity, **E. M. Cohn, P. G. Guest.** United States Department of the Interior, Bureau of Mines, I. C. 7286, June 1944.

3. Apparatus for Determining Minimum Energies for Electrostatic Ignition of Flammable Gases and Vapors, **P. G. Guest.** United States Department of the Interior, Bureau of Mines, R. I. 3753, May 1944.

4. International Critical Tables. Volume 2, page 237.

5. Electrical Charges Produced by Flowing Gasoline. **S. S. Mackeown, Victor Wouk.** *Industrial and Engineering Chemistry*, volume 34, June 1942, page 659.

6. Detecting the Saboteur Static Electricity in Gasoline Fires, **Robin Beach.** *Electrical Engineering*, volume 61, October 1942, pages 501–08.

7. Static Electricity on Rubber-Tired Vehicles, **Robin Beach.** *Electrical Engineering*, volume 60, May 1941, pages 202–08.

8. Static Electricity and Its Effect on Car-Radio Performance, **S. M. Cadwell, N. E. Handel, G. L. Benson.** *Chemical and Engineering News*, volume 19, October 1941, page 1139.

This plant, owned by the Defense Plant Corporation and operated by the Carbide and Carbon Chemicals Corporation, produces butadiene from alcohol

INSTITUTE ACTIVITIES

President Powel Delivers Annual Address in New York

Members of the AIEE New York Section had the unusual opportunity of hearing the annual address of Charles Alfred Powel, president, AIEE, in the auditorium of the Engineering Societies Building, 33 West 39th Street, New York, N. Y., on April 10. This address is normally delivered at the summer technical meeting. Mr. Powel's talk will be published in an early issue of *Electrical Engineering*. George B. Hoadley, chairman, New York section, Institute of Radio Engineers, delivered an address on microwave radio-communication.

The interest of the meeting was further heightened by the showing of two United States Army war films, one depicting the reconstruction of Cherbourg Harbor and the other showing life in bombed German cities taken from captured German films.

Annual Index for 1944 Is Available on Request

As announced (*EE, Mar '45, p 121*) the 1944 index to *Electrical Engineering* and AIEE *Transactions* is being issued in limited edition, available upon written request. The decision to publish the index in limited edition and distribute it separately is a departure from the usual practice of mailing the annual index with *Electrical Engineering* as section 2 of an early issue of the succeeding year. The new procedure represents a further step in the conservation of the restricted supply of paper.

Copies of the index are being mailed without request to all members of AIEE technical committees. In addition, copies are being sent to all subscribers to *Electrical Engineering* and to the "Supplement to *Electrical Engineering*—Transactions Section." To others copies are available without charge and can be obtained by writing to the AIEE order department, 33 West 39th Street, New York 18, N. Y.

Annual Meeting

The annual meeting of the American Institute of Electrical Engineers will be held in the Engineering Societies Building, 33 West 39th St., New York, N. Y., at 10 a.m., Wednesday, June 27, 1945.

At this meeting, the annual report of the board of directors and the reports of the committee of tellers on the ballots cast for the election of officers and for the proposed amendments to the AIEE constitution will be presented. The Lamme Medal will be presented to S. H. Mortensen, and awards of Institute prizes will be announced.

Such other business, if any, as properly may come before the annual meeting may be considered. The officers are not aware that any such other business will be presented.

On account of the Governmental restrictions on conventions, the summer technical meeting, at which the business meeting is normally held, was canceled. Therefore, the annual meeting is to be held at Institute headquarters, and it is expected that the number of out-of-town members attending will be below 50.

(*Signed*) H. H. HENLINE
National Secretary

Fortescue Fellowship Awarded Morton M. Astrahan, the Winner

Morton M. Astrahan, at present attending Northwestern Technological Institute, has been designated the winner of the AIEE Charles LeGeyt Fortescue Fellowship. Mr. Astrahan is a veteran of the present war discharged because of injuries. Before serving in the Army he completed two semesters at Purdue University. After his discharge he entered Northwestern Technological Institute in November 1943 and expects to receive his bachelor of science in electrical engineering in October of this year. His plan is to enter the California Institute of Technology the end of October, and the expenses for the first semester at that institution will be covered by Government aid. The Fellowship award is to cover his second semester at California Institute.

As a memorial to Charles LeGeyt Fortescue, the Westinghouse Electric and Manufacturing Company set up in 1939 a trust fund of $25,000 to provide graduate fellowships in electrical engineering, to be awarded each year by a committee of AIEE. The awards provide a minimum allowance of $500 each.

SECTION • • • • • •

New Technical Groups Formed at Kansas City

Three technical groups, namely, the electronics, industrial electrical practices and problems, and the personal development of the engineer, have been formed by the AIEE Kansas City Section. The electronics group is headed by C. C. Yates (M '42) of the Southwestern Bell Telephone Company. The first meeting already has been held, and the plan is to meet every month for active discussion. The industrial-practices group chairman is N. A. Kieb (M '43) of Pratt and Whitney Aircraft Corporation. This group also plans to have discussions and to use as a text the recent AIEE publication entitled "Electric Power Distribution for Industrial Plants." B. J. George (M '43) of the Kansas City Power and Light Company heads the personal development group. Mr. George intends to raise for discussion the questions of ethics, the ability of an engineer to speak for himself, the professional registration of engineers, and other allied matters.

Michigan Electronics Group Studies Speed Counter. Circuits of electronic instruments was discussed at the first meeting of the newly formed electronics group of the AIEE Michigan Section held in Detroit on March 28. A high light of the occasion was the presentation of instruments for the production-checking of rectifier ripple voltage and for inspection of insulation and arrangement of aircraft wiring harness. An electronic speed counter, utilizing engine ignition as an indication of engine speed, was demonstrated by Paul Huber, assistant director of the General Motors Corporation proving grounds. One hundred persons attended, including 45 AIEE members.

Minnesota Aerotechnical Group Supplies Aero Information

The aerotechnical group, AIEE Minnesota Section, was organized at the beginning of the 1944–45 program to fill the need for discussions on aeronautical subjects. Two Section meetings have been held by the group. The first covered the subject of aircraft electric power plants and distribution problems which was discussed by Colonel T. B. Holliday (M '43) of Wright Field and the second meeting, addressed by W. H. Gille (A '31) of the Minneapolis-Honeywell Regulator Company, covered the subject of aircraft electronics. Slides, motion pictures, operating mock-ups, and samples of apparatus made the programs alive and interesting.

An effort is being made to diversify the programs by organizing special groups and making them responsible for the discussions affecting their particular fields. This is done by planning the organization of a group around one member. The Section chairman chooses a strong man for group chairman and gives him full authority to go ahead and produce results. The group chairman then selects at least two other members to work along with him. Subjects for future programs will include more detailed discussions of aircraft generators and distribution systems, motors for various applications, switchgear, and some of the many different control devices.

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PERSONAL ••••

W. C. Miller (M '26, F '43) superintendent, electrical system, the Detroit Edison Company, Detroit, Mich., has retired after a service record of 45 years. He received his bachelor-of-science degree in electrical engineering from the University of Michigan in 1900 and then entered the employ of the Edison Company as a line and meter engineer. He subsequently held the positions of electrical engineer and assistant and acting general superintendent, and in 1926 became superintendent of electrical system. **H. W. Collins** (A '22, M '42) formerly chief assistant to Mr. Miller, has been named superintendent. Mr. Collins attended the University of Michigan and in 1919 became instructor in the electrical-engineering department. He began working for the Detroit Edison Company in the same year as a field tester, in 1926 receiving the title of relay engineer. In 1929 he became Mr. Miller's assistant and in 1930 was also named project engineer. **D. D. Chase** (A '29, M '39) a member of the company's system engineering staff, succeeds Mr. Collins and becomes his assistant. Mr. Chase received his bachelor-of-science degree in mechanical engineering in 1923 from Kansas State College. Following graduation he was employed by the General Electric Company, Schenectady, N. Y., and became an engineer in the planning division of the electric system of the Edison Company in 1941.

C. W. DeForest (A '07, F '36) vice-president of the Columbia Engineering Corporation, New York, N. Y., and its affiliate, the Cincinnati (Ohio) Gas and Electric Company, has retired. Mr. DeForest gained his early experience with the Brooklyn Edison Company; the United Electric Light and Power Company, New York; and the General Electric Company, Schenectady, N. Y. His association with the Columbia organizations followed its acquisition of the Cincinnati, Newport, and Covington (Ky.) Light and Traction Company of which he was chief engineer from 1903 to 1914. Mr. DeForest then was transferred to the Union Gas and Electric Company, Cincinnati, as electrical engineer. Soon after, he was made manager of the electrical department and vice-president in charge of engineering and operation. Appointed vice-president of the Columbia Power Company in 1925, he later became chief engineer of the Columbia Engineering and Management Corporation, and, when this was liquidated, he returned as chief engineer to the Union Gas and Electric Company. When in 1938 the Columbia Engineering Corporation was formed, he was given charge of the electrical division.

L. T. Rader (A '34, M '43) formerly design engineer, industrial-control engineering department, General Electric Company, Schenectady, N. Y., has accepted the position of director of the department of electrical engineering, Illinois Institute of Technology, Chicago. He was graduated from the University of British Columbia with the degree of bachelor of applied science, electrical engineering, in 1933, and later received the degrees of master of science and doctor of philosophy in electrical engineering, from the California Institute of Technology. After a period with the Canadian Electric Manufacturing Company, Vancouver, British Columbia, Canada, Doctor Rader entered the test department of the General Electric Company in 1937. In 1938, he was transferred to the engineering general department and was given rotating assignments to industrial-control, aeronautics and marine, and induction-motor departments, where he did analysis of special problems and factory contact work, and assisted in the advanced course. In 1939, Doctor Rader designed a-c and d-c solenoids and electromagnets in the industrial-control engineering division, and in 1943 was appointed section head.

E. G. Eidam (A '18) formerly chief telephone engineer, Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y., has been made consulting engineer. Mr. Eidam joined the Stromberg-Carlson Company after graduation from the University of Illinois in 1904. **H. R. Reed** (A '28, M '34) succeeds Mr. Eidam as chief telephone engineer. Doctor Reed attended the University of Minnesota, South Dakota State College, and the University of Iowa. In 1929 he became an electrical tester for the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and served as professor of electrical engineering, Michigan College of Mining and Technology, Houghton, from 1929 until 1932. In 1930, Doctor Reed served as engineer with the United States Army Corps of Engineers and in 1939 worked in a similar capacity with the National Park Service of the United States Department of Interior. Doctor Reed joined the Stromberg-Carlson Company in 1944, after three years as professor of electrical engineering at the University of Iowa, Iowa City.

Adam Pen-Tung Sah (A '35, F '45) president of the National University of Amoy, Fukien Province, China, has been named visiting professor of electrical engineering at Stanford University, Palo Alto, Calif. He will teach a class in a-c machinery to soldier students enrolled in the Army Specialized Training Program. Doctor Sah was graduated from Stanford University in 1924 with a degree in mechanical engineering. Later he studied at Worcester Polytechnic Institute in Massachusetts from which he received the degree of doctor of science. Returning to China in 1928, he was professor of physics and engineering at Tsing-hua University in Peiping for nine years. He returned to the United States on leave for one year in 1935 during which time he did electrical research at Stanford and was a visiting lecturer at Ohio State University and Massachusetts Institute of Technology. He is the author of a book on dyadic analysis and has recently completed the manuscript for a second book on a-c machinery.

C. T. Sinclair (A '19, F '36) chief distribution engineer, Duquesne Light Company, Pittsburgh, Pa., has been appointed chief engineer of the engineering and construction department. Mr. Sinclair was graduated from Lehigh University in 1917 with a degree in electrical engineering. He entered the employ of the Duquesne Company in 1925 as supervisor of transmission and distribution engineering, and later became electrical engineer in the engineering and distribution department. He now is serving on the AIEE Standards committee and American Research Committee on Grounding. **F. S. Brown** (A '12, M '27) electrical engineer, stations division, was made engineer in charge of the electrical-engineering department. He will direct the station, transmission, distribution, customer, and general engineering divisions. A graduate of Worcester Polytechnic Institute in 1907, Mr. Brown came to the Duquesne company in 1910.

W. A. Gentry (M '43) formerly consultant for the Office of War Utilities of the War Production Board, Washington, D. C., has been appointed assistant to the vice-president in charge of operation of the Indianapolis (Ind.) Power and Light Company. Mr. Gentry was first employed with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in 1914 and since that time has been employed by electric utility companies in New York, N. Y., Duluth, Minn., and Charlotte, N. C. He was superintendent of the Memphis (Tenn.) Power and Light Company from 1925 to 1939, and from 1939 until he went to Washington in 1942 he held that position with the City of Memphis.

C. H. Shaw (M '39) consulting engineer, Jackson Heights, N. Y., has joined the firm of Shaw-Rutan, Inc. (formerly Rutan and Snead), New York, N. Y., as president. Mr. Shaw, a 1910 graduate of Massachusetts Institute of Technology, commenced his career with the General Electric Company, which he served from 1910 to 1914 in Cleveland, Ohio. After service as a captain with United States Corps of Engineers in World War I, he was associated for a brief period with the New England Power Company, Worcester, Mass., and Jackson and Moreland, Boston. From 1921 to 1933 he was engineer with the New York Edison Company. Since 1934 he has practiced as a consulting engineer.

George H. Woodard (M '42) has been appointed manager of the newly formed aviation gas-turbine division of the Westinghouse Electric and Manufacturing Company with headquarters in South Philadelphia, Pa. He was formerly manager of the company's new-products division at East Pittsburgh, Pa. Mr. Woodard was born in Schenectady, N. Y., and was graduated from Cornell University in 1928 with a degree in mechanical engineering. He was a development engineer with the Ingersoll-Rand Company in Phillipsburg, N. J., until 1936, when he joined the Westinghouse Company as new-products engineer at the company's steam division in South Philadelphia. In 1941 he was made manager of that division.

E. T. Carlson (A '35) formerly manager of the Norwood (Ohio) division of the Trumbull Electric Manufacturing Company, has been made president of the company. Mr. Carlson was graduated from Northeastern University in 1925, and, after serving as instructor at the university for one year, joined the

Hixon Electric Company as purchasing agent and estimator in 1926. In 1928 he became sales engineer for the Trumbull Company in Boston, Mass., and in 1933 was transferred to Ludlow, Ky., as sales manager. He has been manager of the Norwood division since 1941

T. B. Holliday (A '41, M '43) lieutenant colonel, United States Army, Wright Field, Dayton, Ohio, has been promoted to colonel. Colonel Holliday was at one time instructor, physics department, Purdue University, and was then employed at Wright Field, Dayton, Ohio, where he was junior and later assistant electrical engineer.

J. F. Bailey (A '29, M '35) president of the Georgia Power and Light Company, Valdosta, has also been named a vice-president and director of the Florida Power Corporation, St. Petersburg, where he will make his headquarters.

A. C. Streamer (A '10, M '41) vice-president, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been elected president of the National Electrical Manufacturers' Association.

A. S. McCordick (M '30) vice-president, Moloney Electric Company of Canada, Toronto, Ontario, has been elected a vice-president of the recently organized Canadian Electrical Manufacturers' Association.

A. B. Cooper (M '16, F '33) general manager and vice-president, Ferranti Electric, Ltd., Toronto, Ontario, Canada, has been elected president of the newly formed Canadian Electrical Manufacturers' Association.

C. F. Kettering (A '04, F '14) vice-president in charge of research, General Motors Corporation, Dayton, Ohio, has been elected president of the American Association for the Advancement of Science.

Rolf Selquist (A '25) electrical engineer, Copperweld Steel Company, Glassport, Pa., has been appointed consulting engineer for the company. Mr. Selquist had been electrical engineer since 1928.

T. D. Reimers (M '36) formerly electrical superintendent, Consolidated Edison Company of New York, Inc., N. Y., has been appointed engineering manager of Sheldon Service Company.

L. F. Griffith (M '33) formerly an engineer for the Federal Power Commission, Washington, D. C., has rejoined the staff of the Petroleum Machinery Corporation, New York, N. Y., as a power engineer.

P. B. Stewart (A '25) superintendent, electric-distribution department, Cincinnati (Ohio) Gas and Electric Company, has resigned to go into the appliance business in suburban Cincinnati.

E. H. Hammond (A '34) special representative, United States Civil Service Commission, Los Angeles, Calif., has joined Western Insulated Wire, Inc., Los Angeles, as manager of sales and field engineering.

OBITUARY

Rollin Nichol Conwell (A '15, F '31) transmission and distribution engineer, Public Service Electric and Gas Company, Newark, N. J., died April 14, 1945. Mr. Conwell, who was born February 10, 1885, in Anderson, Ind., attended Purdue and George Washington Universities between 1904 and 1908. Immediately afterwards he conducted acceptance tests and duty trials of the pumping machinery of the Sewer Department of the District of Columbia. In 1911 he joined the Public Service Company as a laboratory assistant. He was named assistant engineer in 1917, transmission engineer of the substation department in 1922, and transmission and substation engineer in 1926. Since 1938 he had been transmission and distribution engineer. Mr. Conwell, inventor of electric relay systems in widespread use, is credited with building up the present high-voltage transmission system of the Public Service Company, which he completely redesigned and reconstructed. He was prominent in organizing the company's system of load forecasting. Mr. Conwell was the author of numerous papers dealing with transmission-line protection problems, one of which he prepared for the World Power Conference held in Japan in 1929. He received the 1931 AIEE national prize for best paper in engineering practice as coauthor of the paper, "Status of Development and Research on Low-Frequency Induction." Extremely active in Institute affairs, Mr. Conwell served on the following committees: telegraphy and telephony, 1922–24; protective devices, 1924–25; safety codes, 1924–27; power transmission and distribution, 1922–37; communication 1928–32; publication 1933–36; co-ordination of Institute activities, 1933–37; award of Institute prizes, 1933–36 (chairman 1933–35); constitution and by-laws, 1935–39 (chairman, 1935–37); and Lamme Medal, 1941–42. He was chairman of the technical-program committee from 1933 to 1935 and represented the AIEE on the American Committee on Marking of Obstructions to Air Navigation from 1933 to 1937 and on the Alfred Noble Prize Committee from 1934 to 1936. He was a member of the special committee on the question of sponsoring discussion on social and economic subjects in 1935. Mr. Conwell held a number of patents in the United States, Canada, and Great Britain, and was a member of many committees of the National Electric Light Association, the American Standards Association, the National Fire Protection Association, and the Association of Edison Illuminating Companies. He also served on the American Committee on Inductive Co-ordination and the Joint General Committee of NELA and the Bell System.

Harvey Morse Cushing (A '06, F '35) consulting engineer, Buffalo Niagara Electric Corporation, Buffalo, N. Y., died January 31, 1945, at Buffalo. Born December 5, 1875, in Rockport, Ind., Mr. Cushing was graduated with the degree of bachelor of science in electrical engineering from the Massachusetts Institute of Technology in 1899. Following graduation he was placed in charge of installing the electric power and light plant for the Janney Manufacturing Company's Works, Ottumwa, Iowa, and in 1900 worked as tester in the dynamo and motor department of the Western Electric Company Chicago (Ill.) factory. In that same year, he became associated with the General Electric Company, Schenectady, N. Y., in the testing department, in 1904 was transferred to the New York sales department, and subsequently served as engineer trouble shooter in the manufacture of apparatus. In 1910 he was appointed local sales engineer for the Buffalo office. In 1915 Mr. Cushing became mechanical engineer, in charge of steam and mechanical design, for the Buffalo (N. Y.) General Electric Company. In 1922 he was appointed chief engineer of that company, and in 1937 was acting in the same capacity for Buffalo Niagara Electric Corporation, where he later became consulting engineer. Mr. Cushing was a member of the AIEE committee on power generation, and a member of the American Society of Mechanical Engineers and American Society for Testing Materials.

Joseph William Herman (A '07) electrical engineer, electrical design department, Burns and Roe, Inc., New York, N. Y., died March 30, 1945. Mr. Herman was born in Riga, Latvia, on August 1, 1883, and became an American citizen in 1905. He was graduated from Cooper Union in 1905 with the degree of bachelor of science, receiving the electrical-engineering degree in 1912. He began work with the General Electric Company, Schenectady, N. Y., in 1905 in the switchboard drafting department. In 1907 he joined the New York (N. Y.) Edison Company as an electrical draftsman and checker, and worked in a similar capacity with Westinghouse, Church, Kerr and Company of New York, and the Electric Bond and Share Company, New York. In 1912, he became chief electrical designer for the Pearson Engineering Corporation, New York, and was then employed in the same capacity by the Chile (South America) Exploration Company. In 1931 he joined the Electric Management and Engineering Corporation, New York, working in electrical design, and was subsequently connected with Gibbs and Hill, New York, specializing in substation design for railroad electrification. Mr. Herman was employed as electrical engineer by Burns and Roe, Inc., in 1936 and was in charge of the electrical design of several modern steam generating stations.

Harry H. Adams (A '06, M '20) former superintendent of shops and equipment for the Chicago (Ill.) Surface Lines, died January 31, 1945, in Evanston, Ill. He was born January 7, 1871, in Jersey City, N. J., and received the degree of mechanical engineer in 1893 from the Stevens Institute of Technology. Between the years 1893 and 1900, Mr. Adams was employed with the Consolidated Traction Company in New Jersey, and later the North Jersey Street Railway Company, where he became master mechanic. He left that company in 1901 to become superintendent of shops in charge of rolling stock and buildings for the United Railways and Electric Company, Baltimore, Md. From 1907 until 1912 he was superintendent of shops and equipment for the receivers of the Metropolitan Street Railway Company, New York, N. Y., and then entered the employ of Ford, Bacon and Davis, New York. In 1913, Mr. Adams became associated with the Chicago Surface Lines, retiring in 1944.

Mr. Adams was at one time president of the American Street and Interurban Railway Engineering Association, and chairman of the committee on standards, American Electric Railway Engineering Association. He was a member of the AIEE traction and transportation committee from 1916 until 1918.

Samuel Graham Neiler (A '94, M '95, F '13) consultant engineer, Neiler, Rich and Company, Chicago, Ill., died February 28, 1945, in Oak Park, Ill. Mr. Neiler, who was born in Erie, Pa., November 14, 1866, received his education at the Massachusetts Institute of Technology and the University of Minnesota, studying mathematics and mechanical engineering. From 1889 until 1890, Mr. Neiler was assistant mechanical engineer for the St. Paul and Sault Ste. Marie Railway, Minneapolis, Minn., and in 1891 he became engineer with Thomson-Houston Electric Company, Boston, Mass. From 1892 until 1894, he was assistant electrical engineer, World's Fair Columbian Exposition, Chicago, Ill., and in 1895 became a member of the firm of Pierce, Richardson and Neiler, Chicago. He became president of the firm in 1911, and served in this capacity until 1913, when he became a member of the firm of Neiler, Rich and Company. The latter firm was succeeded by Neiler, Rich, and Bladen of which he was senior partner. He was a member of the American Society of Mechanical Engineers, the Institution of Electrial Engineers (Great Britain), American Society of Civil Engineers, and vice-president and director of the Electrical Association of Chicago.

William Lester Enfield (A '10, M '15, F '32) development and consulting engineer, lamp department, General Electric Company, Nela Park, Cleveland, Ohio, died on March 21, 1945, in Cleveland. Born March 26, 1879, in Chase, Kans., Doctor Enfield received the degrees of bachelor of science in electrical engineering (1909), and doctor of engineering (1938) from Kansas State College, where he later returned to be instructor in physics. He also attended Kansas State Normal School, the University of Chicago, and Massachusetts Institute of Technology. He entered the employ of the National Electric Light Association, Cleveland, Ohio, in 1910 as engineer in the engineering department, and subsequently became engineer of the manufacturing department (1911), manager of the special engineering department (1913), and manager of the lamp development laboratory (1914), continuing in that position when the laboratory became part of the incandescent-lamp department of the General Electric Company. In 1940 he became consulting engineer. He was an associate of the Society of Automotive Engineers, and a member of the Cleveland Engineering Society.

Edwin Jarvis King Mason (A '07) engineer, the Consolidated Edison Company of New York (N. Y.) died February 23, 1945, at Enfield, Conn. He was born at Suffield, Conn., October 23, 1879. He graduated from Trinity College in 1901 and received the master-of-arts degree there in 1903. He also attended the Rensselaer Polytechnic Institute, where in 1904 he became assistant in the department of electrical engineering and physics. He served two years, from 1908 until 1910, as professor of electrical engineering and physics at the University of Pittsburgh, Pittsburgh, Pa., leaving there to become associated with the Consolidated Edison Company. He served first as general foreman in the test department and instructor in the educational bureau. In 1913 he was appointed engineer in the contract and inspection department, and later became assistant manager in the commercial engineering bureau, now known as the commercial technical bureau. After 26 years with the company he retired in 1936.

David Leonard Lindquist (A '04) chief engineer, Otis Elevator Company, New York, N. Y., died November 11, 1945. He was born September 28, 1874, in Stockholm, Sweden, and graduated from the Royal Technical University there. He spent several years as engineer and draftsman in Sweden and two years as a designer in Berlin, Germany. In 1902 he was employed by the Otis Elevator Company, designing and testing, and was later appointed chief engineer. For his achievements he received the John Ericsson Medal in 1940 awarded by the American Society of Swedish Engineers, and in June of the same year was honored by the King of Sweden, who made him a Knight of the Royal Order of Vasa. Mr. Lindquist was active in the American Standards Association, as a member of the committee on the safety code for elevators, dumbwaiters, and escalators, and of the sectional committee on wire ropes for mines.

MEMBERSHIP • • •

Recommended for Transfer

The board of examiners, at its meeting on April 19, 1945, recommended the following members for transfer to the grade of membership indicated. Any objections to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Anderson, B. E., elec. engr., Ebasco Services, Inc., New York
Currin, H. P., chief elec. engr., Eugene Water Board, Eugene, Oregon
Douglass, F. S., secy.-treas., Laramore & Douglass, Inc., Chicago, Ill.
Kifer, E. H., gen. mgr., City Public Service Board, San Antonio, Texas
Mills, G. A., design and construction engr., Central Pwr. & Lt. Co., Corpus Christi, Texas
Minchrich, M. F., vice-pres., Mokoney Elec. Co., St. Louis, Mo.
Terman, F. E., director, Radio research lab., Harvard Univ., Cambridge, Mass.

7 to grade of Fellow

To Grade of Member

Ballman, E. C., manufacturer, Baldor Elec. Co., St. Louis, Mo.
Bennett, Rawson, Comdr., Navy Dept., Washington, D. C.
Bennett, R. M., asst. design engr., General Elec. Co., Philadelphia, Pa.
Berger, David, secy.-treas., Berger Bros., Toledo, Ohio
Bixby, W. H., assoc. prof. of elec. engg., Wayne Univ., Detroit, Mich.
Bliss, F. W., dist. mgr., General Elec. Co., Boston, Mass.
Brown, W. T., engr., Philadelphia Elec. Co., Philadelphia, Pa.
Browne, T. E., research engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Burt, W. P., requisition engr., General Elec. Co., Philadelphia, Pa.
Case, H. M., general inspector, Western Union Telegraph Co., New York
Clayton, M. B., carrier current engr., Tennessee Valley Authority, Chattanooga, Tenn.
Croney, S. L., marine elec. engr., Atlantic Refining Co., Philadelphia, Pa.
Cuffe, R. C., design engr., Electricity Supply Board of Ireland, Dublin, Ireland
Donald, H. D., elec. engr., Lloyd's Register of Shipping, Vancouver, B. C., Canada
Durfee, B. N., supt. of maintenance, Gilbert & Barker Mfg. Co., West Springfield, Mass.
Falls, C. W., engr., General Elec. Co., Schenectady, N. Y.
Floor, Erik, owner, Erik Floor & Associates, Chicago, Ill.
Fowler, E. B., transmission and plant extension engr., Northwestern Bell Tel. Co., Des Moines, Iowa
Hall, P. R., elec. engr., Bessemer Elec. Service, Bessemer, Ala.
Hayes, V. J., asst. engr., The Connecticut Light & Pwr. Co., Waterbury, Conn.
Hayward, S. K., elec. engr., Northern Indiana Public Service Co., Gary, Indiana
Jacobsen, W. E., elec. engr., General Elec. Co., Schenectady, N. Y.
Kent, H. A., product engr., Sperry Gyroscope Co., Great Neck, L. I., N. Y.
King, C. F., district engr., Westinghouse Elec. & Mfg. Co., Philadelphia, Pa.
Kolin, P. P., member of technical staff, Bell Telephone Labs., Inc., New York
Loomis, E. W., middle Atlantic district mgr., Westinghouse Elec. & Mfg. Co., Philadelphia, Pa.
Matthias, L. H., director of Research, Allen Bradley Co., Milwaukee, Wis.
Mortlock, J. R., asst. to supt. engr., British Thomson-Houston Co., Ltd., London, England.
Muehleman, H. J., operating engr., Hydroelectric Pwr. Comm. of Ontario, Toronto, Ont.
Murray, J. D., elec. engr., Victory Aircraft Ltd., Toronto, Ont., Can.
Norberg, H. A., partner-manager, Nelson Elec. Mfg. Co., Tulsa, Okla.
O'Brien, F. J., elec. engr., Tennessee Valley Authority, Knoxville, Tenn.
Ostaff, Wm., radio engr., U. S. Navy Dept., Washington, D. C.
Pepperberg, L. E., engr., Zenith Radio Corp., Chicago, Ill.
Pye, H. C., development & Research engr., Automatic Elec. Co., Chicago, Ill.
Reed, J. R., field engr., National Electric Coil Co., Columbus, Ohio
Scherrer, G. M., ensign, United States Naval Reserve, Shawneetown, Ill.
Schmidt, E. A., owner, E. A. Schmidt & Co., St. Louis, Mo.
Selvidge, H., assoc. prof. of elec. engg., Kansas State College, Manhattan, Kansas
Sinnott, J. F., protection engr., San Diego Gas & Elec. Co., San Diego, Calif.
Sugden, A. C., asst. elec. engr., The Kellex Corp., New York
Tatum, F. W., engr., American District Telegraph Co., New York
Thompson, H. B., watch electrician, Comunonwealth Edison Co., Chicago, Ill.
Wiederkehr, K. P., elec. engr., Allis Chalmers Mfg. Co., Milwaukee, Wis.
Wood, A. C., consulting engr., Stock Exchange Bldg., Philadelphia, Pa.
Wyatt, C. H., distribution engr., Oklahoma Gas & Elec. Co., Oklahoma City, Okla.

46 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the national secretary before June 15, 1945 or August 15, 1945, if the applicant resides outside of the United States or Canada.

To Grade of Fellow

Tagg, G. F., English Elec. Co., Ltd., Stafford, England.

1 to grade of Fellow

To Grade of Member

Archer, W. D., Jr., Gulf Mobile & Ohio R.R. Co., Meridian, Miss.
Baughman, G. W. (Reelection), Union Switch & Sig. Co., Swissvale, Pa.
Bischel, H. W., Wis. Gas & Elec. Co., Racine, Wis.
Booth, S. W., U. S. Naval Ord. Lab., Washington, D. C.
Bryan, F. E., Vanderbilt Univ., Nashville, Tenn.
Campbell, F. D., Detroit Edison Co., Detroit, Mich.
Chinn, H. A., Columbia Broadcasting System, Inc., New York, N. Y.
Cony, C. J. (Reelection), Duquesne Light Co., McKeesport, Pa.
Crouse, R. C. (Reelection), Civil Aero. Adm., Washington, D. C.
Entwistle, J. L., Pawtucket, R. I.
Ewing, S. C., Gen. Elec. Co., Schenectady, N. Y.
Fischer, B. A. (Reelection), U. S. Naval Academy, Annapolis, Md.
Godfrey, K. L., Godfrey (Pty.) Ltd., Waterloo, N.S.W., Australia
Goldberg, J., Gen. Elec. Co., Schenectady, N. Y.
Heifman, S. J. (Reelection), J. A. Jones Const. Co., Inc., Oak Ridge, Tenn.
Hunter, J. L., Bell Tel. Labs., New York, N. Y.
Kandar, H. M., Krishnanagar, Bhavnagar, Kathiawadi, India
Loomis, H. S., Union Switch & Sig. Co., Pittsburgh, Pa.
Marvin, P. E., Mil. Gas Spec. Co., Milwaukee, Wis.
May, J. W., Wright's Automatic Mchy. Co., Durham, N. C.
McCabe, A. M., Carolina Pr. & Lt. Co., Raleigh, N. C.
McCaw, R. F., Gen. Cable Corp., Rome, N. Y.
McCormick, J. R., N. Y. Rd. of Transp., New York, N. Y.
Myers, R. B. (Reelection), Elec. Engg. & Constr. Co., Des Moines, Iowa
O'Brien, E. F., Lockheed Aircraft Corp., Van Nuys, Calif.
Overby, H. R. S., Royal Norwegian Min. of Sup. & Reconst., New York, N. Y.
Owen, G. E., Antioch College, Yellow Springs, Ohio

Peirson, G. F., Midland Electric Corp., Staffordshire, England
Perkins, L. M. (Reelection), Allen Bradley Co., Milwaukee, Wis.
Powell, D. A., Iowa Pr. & Lt. Co., Des Moines, Iowa
Pritham, C. F. (Reelection), Maine Pub. Serv. Co., Presque Isle, Maine
Schmoetter, E. A., N.A.C.A., Cleveland, Ohio
Shifman, I. W., Lt. U.S.N.R., Cleveland, Ohio
Shortt, H. L., Airadio, Inc., Stamford, Conn.
Smith, J. L. (Reelection), Commonwealth Edison Co., Chicago, Ill.
Swain, O. M., Westinghouse Elec. & Mfg. Co., Lima, Ohio
Tanner, T. J., Eastern Airlines, Miami, Fla.
Taylor, C. W., Admiralty Scientific & Tech. Pool, Helensburgh, Scotland
Terry, F. M., The Insl-X Co., Inc., Brooklyn, N. Y.
Van Zile, L. W., Pub. Serv. Elec. & Gas Co., Irvington, N. J.
Wald, F. O., Utah Pr. & Lt. Co., Salt Lake City, Utah
Warner, A. J., Fed. Tel. & Radio Corp., Newark, N. J.
Weber, R. J., Westinghouse Elec. & Mfg. Co., Pittsburgh, Pa.
White, C. H. M. (Reelection), Stone & Webster Engg. Corp., Boston, Mass.
Zerbi, P. E., Kellex Corp., New York, N. Y.

45 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Allen, W. H., New Hampshire Gas & Elec. Co., Portsmouth, N. H.
Alvarez, W., Gen. Elec. Co., Schenectady, N. Y.
Cerda Echaurren, H., Gen. Elec. Co., Pittsfield, Mass.
Comerford, T. G., Eastman Kodak Co., Rochester, N. Y.
Cooper, B., Gen. Elec. Co., Schenectady, N. Y.
Cowles, L. B., Gen. Elec. Co., Schenectady, N. Y.
Grantz, E. J., Gen. Elec. Co., Schenectady, N. Y.
Hamilton, J. D., Gen. Elec. Co., Schenectady, N. Y.
Herrick, E. R. I. Card Board Co., Pawtucket, R. I.
Kelman, W. L., C. & K. Elec. Co., Providence, R. I.
Kubler, E. F. (Reelection), Gen. Elec. Co., Schenectady, N. Y.
Lockett, R. H., Gen. Elec. Co., Schenectady, N. Y.
McDowell, E. B., Gen. Elec. Co., Schenectady, N. Y.
Moulton, C. D., Gen. Elec. Co., Schenectady, N. Y.
Nelson, J. C., Berger Bros. Elec. Motors, Inc., Rochester, N. Y.
Nolte, R. J., Westinghouse Elec. & Mfg. Co., Boston, Mass.
Perry, W. W., Jr., Gen. Elec. Co., Schenectady, N. Y.
Pflaum, S. M., Berger Bros. Elec. Motors, Inc., Rochester, N. Y.
Rost, L. A., Great American Ind., Meriden, Conn.
Seeger, C. J., III, Cornell Univ., Ithaca, N. Y.
Sills, E. H. (Reelection), Gen. Elec. Co., Schenectady, N. Y.
Stimson, A., Gen. Elec. Co., West Lynn, Mass.
Stokes, J. H., Maguire Ind., Greenwich, Conn.
Troy, J. P., Gen. Elec. Co., Schenectady, N. Y.
Tyll, J. E., Gen. Elec. Co., Schenectady, N. Y.
Wilbur, B., Gen. Elec. Co., Schenectady, N. Y.
Witt, E. T. (Reelection), Stone & Webster Engg. Corp., Boston, Mass.
Yates, C. G., Jr., Gen. Elec. Co., Schenectady, N. Y.

2. Middle Eastern

Baker, R. S., Goodyear Tire & Rubber Co., Akron, Ohio
Baldwin, R. F., Insulation Mfgrs. Corp., Cleveland, Ohio
Connolly, W. J. (Reelection), Safe Harbor Water Pr. Corp., Baltimore, Md.
Diederich, N. F., Clark Cont. Co., Cleveland, Ohio
Dixon, A., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Dyson, W. H., Jr. U.S.C.G. Yard, Curtis Bay, Md.
Evans, J., Glenn L. Martin Co., Baltimore, Md.
Francis, H. R., Dayton Pr. & Lt. Co., Dayton, Ohio
Funk, R. N., Phila. Elec. Co., Philadelphia, Pa.
Gilmer, W. F., Lear, Inc., Piqua, Ohio
Glycadgis, J. M., Lear, Inc., Piqua, Ohio
Goeman, H. G., Dayton Pr. & Lt. Co., Dayton, Ohio
Greene, R. W., Penna. Pr. & Lt. Co., Bethlehem, Pa.
Grigioni, J. D., Cates & Shepard, Philadelphia, Pa.
Heald, S. T., Republic Steel Corp., Cleveland, Ohio
Hornen, H. V., Glenn L. Martin Co., Middle River, Md.
Hoxie, E. A., Elec. Storage Battery Co., Philadelphia, Pa.
Kelley, M. E., Glenn L. Martin Co., Baltimore, Md.
Magee, H. E., Lear, Inc., Piqua, Ohio
McClain, D. D., Glenn L. Martin Co., Baltimore, Md.
McLain, W. J., Dayton Pr. & Lt. Co., Dayton, Ohio
McLaughlin, E., Stockwell Transf. Corp., Akron, Ohio
Miller, G. J., Jr., Western Elec. Co., Inc., Baltimore, Md.
Nagel, E. C., Carbide & Carbon Chem. Co., South Charleston, W. Va.
Schneider, E. V., Alliance Mfg. Co., Alliance, Ohio
Shannon, W. R., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Sherry, R. S., U. S. Navy, Washington, D. C.
Van Roekens, N. H., Phila. Elec. Co., Philadelphia, Pa.
Wallace, C., Westinghouse Elec. & Mfg. Co., Baltimore, Md.
Watkins, N. (Reelection), Carbide & Carbon Chem. Corp., South Charleston, W. Va.
Weadon, R. W., Lear, Inc., Piqua, Ohio
Weiss, M. T., Chief Petty Officer, U.S.N.R., U. S. Naval Lab., Washington, D. C.
Weltzmann, H. P., A. J. LaCourse Elec. Co., Philadelphia, Pa.
Wiecking, W. E., Bell Tel. Labs., Inc., Cleveland, Ohio
Wolfram, P. K., Insulation Mfgrs. Corp., Cleveland, Ohio
Ziegler, F. J., I-T-E Circuit Breaker Co., Philadelphia, Pa.

3. New York City

Boudreau, W. F., Carbide & Carbon Chem. Corp., New York, N. Y.
Braunfeld, M. T., J. A. Tuck, Cons. Engrs., New York, N. Y.
Divitto, A. (Reelection), E. I. DuPont de Nemours, Arlington, N. J.
Fockler, W. G., Allen B. DuMont Labs., Inc., Passaic, N. J.
Haha, A. A., Federal Paper Co., Bogota, N. J.
Hayes, A. E., Jr., Hazeltine Electronics Corp., Little Neck, N. Y.
Heberling, W. W., Jr., Kellex Corp., New York, N. Y.
Hoffman, S., National Design Serv., New York, N. Y.
Krajewski, J. J., Arc Elec. Cont. Co., Inc., New York, N. Y.
Lewinski, J., Radio Receptor Co., New York, N. Y.
Lobo, E., Arma Corp., Brooklyn, N. Y.
Manning, R. H., Sperry Gyroscope Co., Inc., Great Neck, N. Y.
Mealer, R. J., Western Elec. Co., Inc., Kearny, N. J.
Nagel, L. L., Elec. Testing Labs., Inc., New York, N. Y.
Nystrom, H. W., Fed. Tel. & Radio Corp., East Newark, N. J.
Oldmixon, R., Western Elec. Co., New York, N. Y.
Powell, G. S., Fed. Tel. & Radio Corp., Newark, N. J.
Roberts, A. O., Arma Corp., Brooklyn, N. Y.
Roes, L. C., Texas Co., Beacon, N. Y.
Sargent, J. R., G. S. Armstrong & Co., Inc., New York, N. Y.
Selnick, S., Fed. Tel. & Radio Corp., East Newark, N. J.
Sochacki, F. C., Fed. Tel. & Radio Co., East Newark, N. J.
Wisner, F. C., Western Elec. Co., Inc., Kearny, N. J.
Wong, F., Sperry Gyroscope Co., Garden City, N. Y.

4. Southern

Dennison, W. L., Clinton Engg. Works, Oak Ridge, Tenn.
Dickinson, N. K., Tenn. Eastman Corp., Oak Ridge, Tenn.
Jenkins, L. W., Tenn. Val. Auth., Wilson Dam, Ala.
Lipscomb, J. T., Tenn. Val. Auth., Chattanooga, Tenn.
McLaughlin, J. T., Tenn. Val. Auth., Knoxville, Tenn.
McRae, J. T., Jr., Alabama Pr. Co., Birmingham, Ala.
Melugin, D., Tenn. Eastman Corp., Oak Ridge, Tenn.
Percival, A. G., Knoxville Elec. Pr. & Water Bd., Knoxville, Tenn.
Rose, R. B., Gen. Elec. Co., Richmond, Va.
Roth, A. C., Tenn. Val. Auth., Chattanooga, Tenn.
Seefeld, J. T., Eastman Corp., Knoxville, Tenn.
Senatore, S. J., Carbide & Carbon Chem. Corp., Oak Ridge, Tenn.
Smith, C. E., Bell Aircraft Corp., Marietta, Ga.
Snodderly, Z. K., Tenn. Val. Auth., Chattanooga, Tenn.

5. Great Lakes

Albright, R. W., Westinghouse Elec. & Mfg. Co., Chicago, Ill.
Bischmann, O. A., Pub. Serv. Co. of Northern Ill. Chicago, Ill.
Bostater, A. H., Allen-Bradley Co., Milwaukee, Wis.
Camp, B. G., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Deming, G. T., Clack Equipment Co., Buchanan, Mich.
Dever, C. M., Pub. Serv. Co. of Northern Ill., Waukegan, Ill.
Flores Munoz, V., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Foster, L., Foster Elec. Co., Peoria, Ill.
Gardner, M. L., Delco Remy Div., Anderson, Ind.
Germain, G. B., Westinghouse Elec. & Mfg. Co., Duluth, Minn.
Hamilton, R. C., Wis. Tel. Co., Milwaukee, Wis.
Hesse, L., Gisholt Mach. Co., Madison, Wis.
Hewett, J. L., Harza Engg. Co., Chicago, Ill.
Hoelzl, E. A., H. N. Whittelsey Inc., Chicago, Ill.
Kaldenberg, W. G., Iowa Pr. & Lt. Co., Des Moines, Iowa
Kranzush, A. H., Square D Co., Milwaukee, Wis.
Krefting, E., Foster Elec. Co., Peoria, Ill.
Mahn, G. R., Gen. Elec. X-Ray Corp., Chicago, Ill.
Maier, I. W., Sampsel Time Control, Inc., Spring Valley, Ill.
Martin, D. R., Westinghouse Elec. & Mfg. Co., Davenport, Iowa
Meilicke, E. E., Square D Co., Milwaukee, Wis.
Miron, V. C., Wincharger Corp., Sioux City, Iowa
Oakley, T., Ill. Pr. Co., Belleville, Ill.
Oehlwein, O. L. (Reelection), Pub. Serv. Co. of Northern Ill., Chicago, Ill.
Oestreicher, S., Harnischfeger Corp., Milwaukee, Wis.
Peterson, N. L., Cutler-Hammer, Inc., Milwaukee, Wis.
Robel, J. H., Gen. Elec. Supply Corp., Des Moines, Iowa
Sacco, E. J. (Reelection), Westinghouse Elec. & Mfg. Co., Chicago, Ill.
Sachse, E. G., Sr., General Contracting, Peoria, Ill.
Sahlberg, J. W., Pub. Serv. Co., Northern Ill., Waukegan, Ill.
Schultz, F. E., Royal Elec. Mfg. Co., Chicago, Ill.
Seladorf, J. D., Pub. Serv. Co. of Northern Ill., Chicago, Ill.
Swanson, E. S. (Reelection), Pub. Serv. Co. of Northern Ill., Chicago, Ill.
Tapper, H. A., Wis. Elec. Pr. Co., Milwaukee, Wis.
Taylor, R. W., Communications Dept., Chanute Field, Ill.
Tyndall, J. J., Pub. Serv. Co. of Northern Ill., Waukegan, Ill.
Van Duser, C. E., A-C Supply Co., Inc., Milwaukee, Wis.
Vater, G. W., Allen-Bradley Co., Milwaukee, Wis.
Woodward, R. V., Dowser Elec. Mchy. Works, Mt. Vernon, Ill.
Wright, P. H., Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.

6. North Central

Fuller, J. F., Gen. Elec. Co., Denver, Colo.
Kiesling, P. W., Pub. Serv. Co. of Colo., Denver, Colo.

7. South West

Orechetti, F. (Reelection), Rural Elec. Adm., St. Louis, Mo.
Corcoran, A. E., Transcontinental & West. Air, Inc. Kansas City, Mo.
Green, R. L., Dick X-Ray Co., St. Louis, Mo.
McClure, R. F. (Reelection), Southwestern Pub. Serv. Co., Plainview, Texas
Peterschmidt, J. E., Walco Engg. & Const. Co., Tulsa, Okla.
Ury, J. M., Curtiss-Wright Corp., Robertson, Mo.

8. Pacific

Beeson, M. L., County of Los Angeles, Los Angeles, Calif.
Brettell, G. A., Jr., Univ. of Calif., San Diego, Calif.
Demaree, D. M., Goodyear Aircraft Corp., Litchfield Park, Ariz.
Edgecomb, H., Moore Dry Dock Co., Oakland, Calif.
Gustovich, G., Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.
Haines, A. S., Marine Corps Air Depot, San Diego, Calif.
Hoskins, J. W., Supt. of Shipbldg., U. S. Navy, San Francisco, Calif.
Hoyt, F. R., W. E. Camp, Sacramento, Calif.
Kastl, R. H., U. S. Navy, San Francisco, Calif.
Knowlton, C. R., Lt. Comdr., U.S.N.R., San Diego, Calif.
Louie, W. H. W., Calif. Shipbldg. Corp., Wilmington, Calif.
Mack, C. D., San Diego Gas & Elec. Co., San Diego, Calif.
Moninger, M., Southern Calif. Tel. Co., Los Angeles, Calif.
Nassir, N., C. F. Braun & Co., Alhambra, Calif.
Oberholtzer, J. M., North American Avia., Inglewood, Calif.
Pabst, R. E., Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.
Raine, S. D., U. S. Navy, Hunter's Point, Calif.
Suykerbuyk, C. P., Allis-Chalmers Mfg. Co., Manhattan Beach, Calif.
Waller, J. E., U. S. Navy, Camp Parks, Calif.
Ward, P. E., Sacramento Air Serv. Tech. Comm., Sacramento, Calif.
Webb, A. H., Waugh Labs., Pasadena, Calif.
White, T. D., Cent. Ariz. Lt. & Pr. Co., Phoenix, Ariz.

9. North West

Burdick, R. L., Northwestern Elec. Co., Vancouver, Wash.
Dawson, J. R., Electric Smith Co., Spokane, Wash.
Duryee, S. L., Pac. Tel. & Tel. Co., Seattle, Wash.
Eisele, L. A., Washington Water Pr. Co., Spokane, Wash.
Hammond, W. M. (Reelection), Northwestern Elec. Co., Vancouver, Wash.
Ittner, C. K., Alum. Co. of America, Troutdale, Oreg.
Sargent, M. J., Northwest Electronics Co., Spokane, Wash.
Wolgast, L. H., Alum. Co. of America, Troutdale, Oreg.

10. Canada

Baker, N. W. G., Ontario Hydro Elec. Pr. Comm. Toronto, Ont., Can.
Canniff, F. H., National Defense Dept., Ottawa, Ont., Can.
Carriere, R. J., Allanson Armature Mfg. Co., Ltd., Toronto, Ont., Can.
Duchastel, P. A., National Res. Council, Ottawa, Ont., Can.
Howard, H. A., Brantford Township Hydro Elec. Comm., Brantford, Ont., Can.
Kierans, W. P., Montreal Tramways Co., Montreal, Que., Can.
Stevenson, W. R., National Res. Council of Can., Montreal, Que., Can.
Walker, W. E., Montreal Tramways Co., Montreal, Que., Can.
Wright, C. A., Can. Gen. Elec. Co., Toronto, Ont., Can.

Elsewhere

Beynon, T. C., Forbes Mun. Council, Forbes, N.S.W., Australia
Buckland, E. A., British Thomson-Houston Co., Ltd., Rugby, England
Butterworth, E. G., Elect Lt., R.N.V.R., Bath, England
Chabook, R. D., Hyderabad Elec. Syndicate, Hyderabad, India
Du Toit, P. J., Victoria Falls & Trans. Pr. Co., Transvaal, South Africa
Marcroft, R. L., Ministry of Munitions, Melbourne, Australia
Masumdar, B. C. (Reelection), Dir. Gen. Shipbldg. & Repairs, Bombay, India
McMullen, W. F., Lt. Col. (Reelection), Canadian Army Overseas, B.W.E.F.
Pollard, A. R., Winchester Corp., Winchester, England
Rammohan, S., Indian Iron & Steel Co., Ltd., Kulti, India
Rao, S. R., Callender's Cable & Const. Co., Bombay, India
Saborio M., J. R., Dept. Elect. Mun. Alajuela, Costa Rica, C.A.
Santoman, A. J., United Provinces Elec. Supply Co., Ltd., Lucknow, India
Selle, E. M., Emp. Elec. del Depto. de Chimaltenango, Guatemala City, Guat., C. A.
Shimmins, A. J., Precision Measurements Gen. Res. Labs., Melbourne, Australia

Total to grade of Associate
United States and Canada, 189
Elsewhere, 15

OF CURRENT INTEREST

Bills Reflect Patent Commission's Recommendations

The National Patent Planning Commission's recommendations (*EE, Sept '43, pp 423–4*) are carried out in three new bills on patents recently introduced in Congress by Representative F. W. Boykin, chairman of the House committee on patents. The major proposal, HR 2632, would require the recording of agreements relating to patents. Another bill, HR 2630, would provide for the public registration of patents available for licensing, and HR 2631 proposes that a patent shall terminate not more than 20 years after an application has been filed but keeping the term of a patent at 17 years.

These bills have been endorsed by the National Association of Manufacturers, whose chairman R. J. Dearborn has gone on record in favor of enlarging the Patent Office staff to permit a thorough examination of every application and thus correct one serious weakness in the system.

WAR PROGRAM

Tramway Built to Evacuate Wounded on Italian Front

Using for the first time in combat a trick they practiced diligently in the Rocky Mountains, engineers of the tenth "Mountaineer" division recently built a 1,500-foot cable tramway for evacuation of the wounded from the Fifth Army front in Italy. The tram, which carries supplies on the up trip, reduced the average time it takes to evacuate a casualty, from between 3 and 5½ hours, to five minutes. The tramway is 450 feet higher on the ridge than it is at its base. Construction of the tram required only nine hours. Suspended from half-inch wire cable supported by two A frames built to sustain tension stress and powered by a gasoline engine, the lift will bear 350 pounds. It is pulled by quarter-inch wire cable. Italian soldiers pioneered in cable tramways during the World War in fighting in the Alps Mountains, where they assembled 1,200 miles of them. Engineers of the Tenth Division studied their methods while in training and built several tramways near Camp Hale, Colo.

Government Needs Electrical Engineers

The United States Civil Service Commission is making an extensive recruiting drive to provide electrical engineers for essential war work in the Signal Corps, in the Bureau of Ships of the Navy Department, in offices of the Rural Electrification Administration, and in various Federal agencies in Washington. Engineers not now engaged in war work are urged to consider these opportunities. The appointments are war service appointments and are made in accordance with War Manpower Commission policies and employment stabilization programs. Applications may be obtained from the Commission's local representatives at first- and second-class post offices throughout the country, or from the Commission, Washington 25, D. C.

Radio–Radar Equipment Discussed. Promoting war production of radio–radar equipment was the principal topic of joint meetings held at the Mount Royal Hotel in Montreal, Canada, on April 25–26 by officials of the United States and Canadian Governments, with the two boards of directors and officers of the American and Canadian Radio Manufacturers Associations. Present also were Army and Navy officers and directors of radio and radar divisions. Mutual problems of the war program and of the American and Canadian industries were discussed, and further co-operation between the neighboring organizations of radio-manufacturers' associations was suggested.

Electric Power Will Hasten Italy's Industrialization

Industrial production in liberated Italy will be increased shortly as additional electric energy becomes available, according to an announcement of the Allied Commission. The increased production will result directly from a larger allocation of power for civilian use. Production of superphosphate fertilizer, carbon bisulphide, cotton and woolen textiles, sewing thread, and other items will be started. At the same time, operation of mercury, sulphur, pyrite and lignite mines will be improved, principally in the area north of Rome between Terni and Florence. The bringing into production of manufacturing and mining operation is made possible because of improved electric output in the area served by the Central Italy Grid System. One larger power plant which will be added to the system will increase the power output by approximately 25 per cent. The Central Italy Grid System covers the area from the Garigliano River (above Naples) to Florence on the north and Ancona and Rimini on the northeast. In one important industrial area electric power available was increased to 33,500 kw in the month of April from 21,000 in March.

Installed electric generating capacity for Central Italy will soon be increased to 285,000 kw, an increase of 40 per cent in two months, bringing it to a level more than five times what it was when this region was liberated. This increased capacity, however, does not yet compare with prewar capacity of 1,292,336 kw.

Telephone Facilities of Liberated Countries Are Restored

United States Army Signal Corps soldiers are rehabilitating telephone facilities of liberated European cities for the use of Allied Armies as they move forward. European cities customarily utilize sewers as conduits for telephone cables, but officers and enlisted men put on hip boots and carry out essential repairs and make new installations. Numerous cities, in France especially, have been brought into adequate and reliable contact with the directing agencies and with the battlefronts, thus serving as added links in the expanding system of military communications serving the western front. The use of sewers for telephone cables is prompted by Europe's perennial need to be economical in all civic installations. In American cities such underground cables usually are installed in vitrified clay conduits providing ducts only slightly larger than the cables which are pulled through by means of wire. Manholes are located on the duct lines approximately a city block apart, permitting splicing at convenient points. In the sewers of France the lead cables are merely racked along the dank walls.

The final operation in rehabilitating telephone facilities consists in testing the cables and splicing them into the main control board of the city. One of the signalmen follows a cut sheet called the "brains," showing how the various pairs are to be spliced. Wires are scraped bare of insulation at the necessary points and the connecting wires are pigtailed to them, after which waxed cotton sleeves are adjusted to give these connections protection.

Substitutions in Signal Equipment Made by Army

United States Army Signal Corps has made substantial contributions in devising substitutes for strategic materials needed for signal equipment. This program has included basic research in developing new alloys, ceramics, and glass, and the work of testing and trying scores of substitute materials in practical application. A few which have been developed or sponsored by the United States Signal Corps are the following:

Low-grade mica for low-voltage capacitor applications.

Plastic materials for flashlights and signal lamps and special light projectors.

Plastic insulation for wires.

Magnesium instead of steel or aluminum or wood in radio chassis, antenna masts, and antenna mounts.

Plasticized ceramics developed as a substitute for mica in the manufacture of condensers.

Plasticized laminated paper and wood fiber in place of plywood.

Insulators made of glass instead of certain critically short ceramics.

Vibration absorbers, or shock mounts, made of substitutes for rubber.

Meteorological balloons made of substitutes for rubber.

Aviation Gas-Turbine Division Formed. Formation of an aviation gas-turbine division for the manufacture of military and, later, commercial gas-turbine aircraft engines, based on the jet engine, has been announced by L. E. Osborne, vice-president of Westinghouse Electric and Manufacturing Company. Manager of this division will be George H. Woodard whose headquarters will be at the South Philadelphia Works of the company. Reinout P. Kroon has been named manager of the engineering department.

INDUSTRY . . . . .

New Voice to Be Heard on Chilean Front

Station CB114, recently scheduled to go into operation, will be the first long-wave broadcast station to reach cities and towns throughout the 2,600-mile length of Chile, according to the Radio Corporation of America international division, whose Chilean company designed and built the station. CB114 was designed and built by Corporación de Radio de Chile, manufacturing subsidiary of RCA in Santiago. It is now owned and will be operated by the Corporación Chilena de Broadcasting, headed by Adriano Iz Reyes, station operator in Vina del Mar, Chile.

Completed on the plains outside the capital city of Santiago, this 50-kw station has been specially designed and situated to overcome the long-wave radio-transmission problems presented by Chile's rugged topography and long narrow geographical configuration. Because of these characteristics, the country heretofore has been dependent on short-wave broadcasting for national coverage.

The Corporación de Radio de Chile revealed that CB114's national coverage was achieved largely by means of a special type of directional antenna and an elaborate ground system which concentrate broadcast energy generally northward and southward. Although the station has a rated power of 50 kw, the special antenna and ground system provide an unmodulated carrier power of 135 to 140 kw to the North and South. The antenna is designed in a special pattern to fit the curve of the country. As its designation indicates, it will operate on a frequency of 1,140 kilocycles.

The plant incorporates a modern style of vertical-panel construction; an RCA 50-*E*-type transmitter, the same type as used by many United Nations broadcasting stations; complete automatic protection; air-cooled power tubes; a modern two-color streamlined enclosure; and a high-efficiency modulating system. Two transmitting masts, each 300 feet high and having a dead weight of 36 tons, are surrounded by an underground network of 22 miles of four-millimeter copper wire to assure high antenna efficiency.

Studios in downtown Santiago, equipped with high-fidelity RCA equipment, will pipe the programs to the transmitter either by telephone lines or by an ultrahigh-frequency link transmitter built in RCA's Santiago plant. Facilities are provided for handling four studios simultaneously, as well as for recording.

Nomograph Charts Issued for Radio Engineers

Nomograph charts never before available, providing radio engineers with an invaluable tool in the design of equipment for the ultrahigh-frequency and television ranges, have been issued by the Federal Telephone and Radio Corporation of Newark, N. J., associate of the International Telephone and Telegraph Corporation. The set now being offered, 25 in number, represents the beginning of a projected series of more than 100 graphic aids to the designer of radio, ultrahigh-frequency, and television equipment. Six of the charts now being offered are for use in the design of double- and triple-tuned band-pass circuits in the ultrahigh-frequency and television ranges, and provide a quick and easy means of answering the questions which arise in the design of such circuits. Two of the nomographs cover series and shunt-peaking methods of range extension in wide-band amplifiers, and other charts relate to impedance characteristics in various types of transmission lines, including single wires in troughs and in square outer conductors; balanced two-wire and concentric lines, air-spaced, and with solid dielectric; quarter-wave matching sections, and sending-end impedance in uniform lines.

Other charts treat transmission-line lengths, cutoff frequencies in circular wave guides, ultrahigh-frequency path lengths and optical line-of-sight distances. The remainder of the charts allow rapid calculation of deflection sensitivities of cathode-ray tubes, modulation percentages from oscillograms, reduction in gain caused by feedback, and dissipation of power in water-cooled devices.

Relay Stations Will Be Constructed. The American Telephone and Telegraph Company has filed application with the Federal Communications Commission for authority to construct seven relay stations between the terminals of the New York–Boston radio-relay project. FCC approval on the two terminals was granted last year. This route was selected for the experimental trial of microwave radio relay because of its nearness to the Bell Telephone Laboratories in New York and because of the continuing need for additional facilities between these two cities. The New York–Boston experiments are planned in three parts of the radio-frequency spectrum—near 2,000, 4,000, and 12,000 megacycles. Eight channel assignments, each 20 megacycles wide, are being requested in each of these parts of the spectrum.

Short-Wave Station in New Brunswick

Station CHTA, short-wave radio station in Canada, is beaming programs in several languages to Europe and soon will cover the world. This Government-owned station was built at Sackville, New Brunswick, in the salt marshland area. Its towers and antennas are designed to resist winds of 120 miles per hour. It is equipped with two transmitters each generating 50,000 watts, but a special beam antenna multiplies this 100 times, giving a total available power of 10,000,000 watts to the station. More than 26 miles of wire are used for the antennas and conducting lides between them and the transmitters. The antennas are strung up between towers varying in height from 170 feet to 380 feet. On the Great Circle Route, this particular location is one of the few places in Canada free of the north-magnetic-pole influences.

Power Project for Oregon Planned

The California Oregon Power Company, Yreka, Calif., has filed an application with the Federal Power Commission for a preliminary permit to construct a 40,000-kw hydroelectric project on the North Umpqua River in Douglas County, Oreg., 50 miles east of Roseburg. There have been few filings for permits for large power projects since the war began.

To be known as the Toketee Project, the proposed development would consist of a diversion dam about 500 feet downstream from the mouth of the Clearwater River; a tunnel in rock about 7,000 feet long across a bend in the river; a double line of steel penstocks; and a powerhouse with two 20,000-kw units.

It is the plan of the company to deliver the power to public and wholesale customers including Mountain States Power Company and Pacific Gas and Electric Company.

"Newsfront" Makes Debut. The initial issue of Westinghouse *Newsfront*, a new monthly publication by the Westinghouse Electric and Manufacturing Company, appeared in April. Featured in the first issue are the company's annual report, a story on a new application of the Precipitron air cleaner for the removal of "fly-ash," and a picture page illustrating recent Westinghouse developments. A four-page report, printed in two colors and illustrated contains short articles describing the latest achievements by the company in the fields of scientific research, engineering, and production.

New Synthetic Rubbers Put to Use. Fifty-three new synthetic rubbers were produced in the three synthetic rubber plants operated by United States Rubber Company during 1944, according to J. P. Coe, general manager of the company's Naugatuck chemical and synthetic-rubber divisions. Of these new rubbers eight types have been adopted for regular use in the manufacture of rubber insulation of electric wire and cable, porous-rubber storage-battery separators, asbestos sheet packing, and pressure-sensitive adhesives. Of the other 45 types, many are being evaluated. This work is being carried out under the supervision of Rubber Reserve Company as part of the Government's synthetic rubber program.

"Locomotive" Tests Radio Equipment. A highway "locomotive" is helping engineers in Baltimore test very high-frequency radio equipment for railroad radio communications. Cruising within a radius of ten miles from the radio and electronic laboratories of the radio division of Bendix Aviation Corporation, the "locomotive," a specially fitted truck, tests newly designed radio equipment under conditions approximating railroad operation. On daily runs radio technicians in the truck report continuously to other engineers at the plant laboratory by radio on changes in terrain being traveled by the truck. Records are kept at the plant of differences which occur in reception quality when the truck passes buildings, wires, or any types of electrical installations. Data are being compiled on the relative merits of amplitude-modulation and frequency-modulation equipment for mobile communications. On the daily runs the truck engineer switches from amplitude modulation to frequency modulation every ten seconds to provide comparative data.

"Heat in Harness" Course Is Given. An educational program in the heating industry has been initiated by the Minneapolis-Honeywell Regulator Company for interested persons associated with automatic heating. The courses are held in all sections of the United States where company branches are maintained and will cover four 2½-hour meetings. More than 800 slides supplement the simple lectures which are conducted by company sales engineers who have been specially trained for the purpose. The primary purpose of the program is to teach the application of automatic controls and their installation and maintenance, in connection with the various types of heating systems using all kinds of fuel. In planning the course the company also had in mind the rehabilitation of men of the Armed Forces who by prior experience or by choice want to find jobs in some phase of the heating industry.

Demonstrate Uses of Wire Recording. Developments in wire recording and its uses for home entertainment, radio recording, office dictation, and the recording of telephone conversations were demonstrated recently by Lear, Inc., and by the Stromberg-Carlson Company. When wire recording is used for dictation in the business office, errors can be "erased" automatically while the correct words are inserted over the same portion of the wire. The improved models record and play back music with high fidelity which will assure their postwar application to the home radio receiver. Unwanted programs can be "erased" from the hair-thin wire to permit reuse. This eliminates costly upkeep and reveals a practical recording method where recording or dictating unwanted things need not result in loss to the user. Research work on wire recording has been conducted for many years.

Single-Crystal Transmitter Developed. A compact eight-channel mobile-service transmitter, which can be set for any frequency in the 100–156-megacycle band and uses but one crystal, has been developed by the radio division of the Bendix Aviation Corporation. It is usable in any type of mobile service and can be quickly converted from amplitude modulation to frequency modulation. A new three-dial eight-channel automatic shifter used in the unit has possibilities in multichannel applications. The number of dials could be varied on the basic design from one to ten, and as high as 16 channels ultimately could be incorporated into design. On any one of the eight channels, frequencies are determined accurately by dial calibration without the use of a crystal frequency indicator. The new transmitter was designed by R. B. Edwards of the division's transmitter engineering department.

OTHER SOCIETIES

Advances in "Movies" Will Be Presented. The 57th semiannual technical conference of the Society of Motion Picture Engineers will be held May 14–18, 1945, in Hollywood, Calif. Advances in wartime military and naval use of motion pictures and in theater television, motion-picture sound recording and reproduction, and motion-picture photography and projection will be presented at nine technical sessions during the five-day conference. The use of film in television programs and the relationship of television and motion-picture practices are among the topics of scheduled papers.

ASA Plans Standards for Drafting Practices

The American Standards Association at the request of the War Production Board is developing a series of American War Standards for drawing- and drafting-room practice that will correlate the practices of the Army and Navy with those of industry. ASA has long had a regular committee on drawing- and drafting-room practice working under the joint technical leadership of the American Society of Mechanical Engineers and the Society for the Promotion of Engineering Education. Standards developed by this committee have laid down the simple basic elements of the subject. This new work proposes to carry the subject further into the realm of modern industrial production.

Work on these new War Standards, which has already been started, is being financed by the War Production Board through an already existing Government contract under which the ASA since July 1942 has completed 88 Standards of direct concern to the war effort and has under development some 68 more.

The War Department has outlined the scope of the work to include civil, mechanical, electrical, aeronautical, and marine engineering, and such subjects will be covered as the following: abbreviations; methods of indicating and specifying threads; methods of lettering; drawing forms and sizes; graphical, diagrammatic and schematic symbols; methods of indicating and specifying materials; methods of indicating and specifying finishes; methods of dimensioning and indicating tolerances; and methods of numbering drawings.

New Radio Section Formed. A new section of the Institute of Radio Engineers, the Cedar Rapids section with 118 members, has been formed. At the April 11 meeting R. L. Campbell and R. E. Colander presented papers. Mr. Campbell discussed quartz crystals from a structural point of view and Mr. Campbell's paper dealt with circuit functions of piezoelectric crystals. At the March 19 meeting at the Hotel Roosevelt in Cedar Rapids 96 persons were present and heard the guest speaker W. L. Everitt (A '25, F '36) national president of the Institute of Radio Engineers, talk on wartime development of electronics. Officers were elected and installed for the year 1945.

RESEARCH

Scientists Will Co-ordinate Research Work

Through the formation of a $2,000,000 corporation uniting their efforts, electronic scientists of International Telephone and Telegraph Corporation functioning in the United States and numerous other countries will be grouped in a world-wide organization, with headquarters in the United States. The scientific corporation, formed in Delaware as International Telecommunication Laboratories, Inc., was created to make possible ultimately an exchange of inventions and closer co-ordination of the corporation's electronic research work, including advancements in radio, television, and other branches of the communications arts and the aids to aerial navigation which they will afford in the postwar era.

E. M. Deloraine, general director of Federal Telephone and Radio Laboratories, New York, is president of the organization. The corporation is owned jointly by International Telephone and Telegraph and a subsidiary, International Standard Electric Corporation. Among the other officers elected were Harold H. Buttner and Douglas B. Baker (M '27) vice-presidents; Paul F. Swantee, comptroller; O. C. Buchanan, treasurer; and C. Douglas Webb, secretary.

EDUCATION

Course Offered in Iowa City. A three-week management course is being offered again this year by the State University of Iowa in Iowa City from June 11 to June 29. Designed primarily for people in industry who want comprehensive training in production planning, plant layout, motion-and-time study, and wage incentives, the program includes fundamental training with practical applications. The course will benefit especially those executives who are responsible for reducing manufacturing costs and increasing production. Attention will be given to procedures to be followed in conducting factory training programs in this field. Conducted as it has been for the past seven years, the course will be held under the direction of Ralph M. Barnes, professor of industrial engineering at the university. Tuition and laboratory fee for the three-week course is $150. Advance registration is required, for enrollment will be limited, and applications will be accepted in the order of their receipt.

Appropriations for Pursuit of Science. Because the Rockefeller Foundation believes that the United States has wasted its scientific patrimony for war needs, appropriations have been made from limited funds to train young men under the auspices of the National Research Council and the Social Science Research Council. In a 63-page review of the foundation's work during 1944 Raymond B. Fosdick, president, contrasted the methods of this country with Russia and England where the future is protected by guarding the flow of new scientific personnel. He stated that in Russia students of ability in science are not permitted in the Armed Forces whereas in the United States scientific professors and students alike largely have left the universities. The report stated that the foundation financed nine projects in the natural sciences in England last year, seven in Sweden, and two in Switzerland. Doctor Fosdick praised the scientists who made their laboratories available to refugee scientists.

Proposed Headquarters for Electronic Research

The designer's conception of new laboratories, the first unit of which is now under construction at Nutley, N. J., for postwar activities of International Telecommunication Laboratories, Inc.

HONORS

Scientific High Command Donates Award to Academy

The six American scientists foremost in mobilizing the country's scientific resources for war recently were honored with the eighth annual American Design Award, and at their request the award was presented to the National Academy of Sciences as the body that represented all scientific endeavor in America. Presentation of the $25,000 check and accompanying certificate recognizing the organizers of the means for creating new weapons, new airplanes, and vehicles; new medicines; and new materials was made by Walter Hoving, president of Lord and Taylor, New York, N. Y., donors of the award. Frank B. Jewett (F '12) president of the academy, accepted the award on its behalf.

The scientists so honored were: Vannevar Bush (F '24) director, Office of Scientific Research and Development; James Bryant Conant, chairman, National Defense Research Committee; Karl T. Compton (F '31) chief of the field service for the NDRC; A. Newton Reichards, chairman, Committee for Medical Research; Jerome C. Hunsaker, chairman, National Advisory Committee for Aeronautics; and Ross G. Harriman, chairman, National Research Council.

Speakers at the ceremonies included Doctor Compton, Doctor Jewett, and Mr. Hoving.

Doctor Compton warned that, "if we are not to become an easy and inviting prey to the next well-prepared aggressor, we must be alert to be ourselves prepared to meet what may come." "In order," he said, "that the United States may be safe it must be just and co-operative in its international dealings, but it must also be strong internally." Stressing scientific preparedness as one aspect of this strength, he stated that no nation would attack us again, unless it were convinced of a speedy victory by superior technical methods. "The Nazis, Fascists, and Japs were encouraged, not deterred, by the pledges of our youth never to bear arms, or by our refusal to strengthen the defenses of Guam, or to mount modern guns on Corregidor," he declared.

Doctor Jewett pointed out that wartime co-operation among scientists augured well not only for a more decent postwar world but for a greater national security. The award money, he added, would be spent "in the encouragement of research in those things which are deemed most likely to enhance the security of our country."

Alexanderson Receives Swedish Gold Medal

Doctor E. F. W. Alexanderson (F '20) consulting engineer, the General Electric Company, Schenectady, N. Y., has been awarded the Cedergren gold medal of the Royal Institute of Technology, Stockholm, Sweden. The medal, which was instituted by the will of the late Henrik Tore Cedergren, telephone pioneer of Sweden, has been conferred upon Doctor Alexanderson, "not only as a tribute to a great man of science, but

also as a symbol of international friendship and co-operation."

In his presentation of Doctor Alexanderson for the award, Harry Stockman, Harvard University, lauded his personal character as well as his attainments in the field of electrical engineering. "Doctor Alexanderson's outstanding characteristics are his lack of fear of difficulties, his accomplishment of the seemingly impossible, his straightforward manners, and his honest approach to his work. These traits were much in evidence in his design of an alternator for a frequency of 100,000 cycles per second, an alternator which everyone thought could not be designed; in his execution of a specially ventilated 1,500-volt d-c motor with which he won an international competition in Melbourne, Australia; and in his work in facsimile transmission and television. In recognition of his ability, in 1940 Doctor Alexanderson's name was listed on the New York World's Fair 'Wall of Fame' honoring foreign-born citizens who have made notable contributions to American democracy."

The Cedergren medal was presented to Doctor Alexanderson by the Swedish Consul General, Martin Kastengren, at a dinner of the American Society of Swedish Engineers held on February 9, 1945, at the Restaurant Stockholm, in New York, N. Y.

A. H. Compton Receives 1945 Washington Award

The Washington Award for 1945 has been conferred upon Arthur Holly Compton, dean, division of physical science, and chairman, department of physics, University of Chicago.

The Washington Award was established in 1916 by Past President Alvord of the Western Society of Engineers and is presented annually by the Washington Award Commission, composed of nine representatives of the Western Society of Engineers and two each from the American Society Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, and the AIEE, to the engineer who has done some outstanding work or whose services in general have been directed toward promoting the public good.

POSTWAR . . . . . .

Veterans From Colleges to Organize. The first veterans' organization on a national scale to grow out of World War II has been announced by the organizing chapter at the Polytechnic Institute of Brooklyn. The new association, known as the Gamma Iota Alpha ("GI Association") is for honorably discharged members of any branch of the Armed Forces who are attending college or who have attended college. Servicewomen also are entitled to join the association. The founding chapter at Polytechnic Institute is acting as national headquarters for the organization until such time when a meeting can be held and a permanent constitution drawn up. Announcement of this proposed intercollegiate veterans' organization has been forwarded to 800 colleges and universities in the United States. Information for installing chapters already has been forwarded to groups at Illinois Institute of Technology, Duke University, Ohio State University, Lehigh University, Louisiana State University, University of North Dakota, University of Wyoming, Boston University, Pratt Institute, Brooklyn College, and Queens College. Beta and Gamma Chapters are active in St. John's University and Long Island University.

JOINT ACTIVITIES

New Canadian Council Formed. A new national body has been formed in Canada with headquarters in Ottawa called the Canadian Council of Professional Engineers and Scientists. The main purpose of the council is the co-ordination of all aims and efforts of Canadian engineers and scientific workers on matters affecting the public interest in general and the professional interest in particular. Matters such as collective bargaining, ratings in the Armed Forces, national selective service, postwar employment, national-research policies will be dealt with by the council, and through its formation Canadian Government departments now will have one direct channel of approach for all questions of legislation which concern professional engineers and scientists. With the establishment of a liaison officer in Ottawa having close connections with the Dominion Government, interests of engineers may be surveyed more adequately before legislation is enacted rather than after it becomes a legal statute. At present the body functions as a council on which the senior officer of each supporting society acts as a voting member. W. J. Gilson vice-president, AIEE District 10, Eastern Power Devices Ltd., Toronto, Ontario, Canada, will supply information to those interested.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication herein no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Calculating Antenna Radiation Patterns

To the Editor:

I wish to clear up a misunderstanding in the discussion of "Calculating Antenna Radiation Patterns" by R. W. Cronshey (*EE, Sept. '44, pp. 331–4*). In Mr. Cronshey's reply to my letter in the March issue of *Electrical Engineering*, he is quite right in stating that, if the square-root signs were inserted in all places mentioned, the calculations would still be correct. The results given in the original article would then be true for $\sqrt{(P_D/P_A)} = 1/2$ or $P_D/P_A = 1/4$ (see Table I, column 4).

My calculations were designed to give the results for the power ratio $P_D/P_A = 1/2$, as implied by the original article. However, I inadvertently took $\sqrt{(P_D/P_A)} = 1/4$ instead of $1/\sqrt{2}$, thus leading to erroneous and confusing results. For the power ratio $P_D/P_A = 1/2$, the correct figures are: $\sqrt{(P_N/P_A)} \sin = 0.62$; $\sqrt{(P_N/P_A)} \cos = 0.34$; $Y = -1.28$; $X = 0.79$; $E_P/E_A = 1.50$.

With this correction made, I am sure that we are in full agreement as to the results.

HERBERT L. KRAUSS (A '42)

(Assistant professor of electrical engineering, Yale University, New Haven, Conn.)

Applications of Thevenin's Theorem

To the Editor:

Walther Richter's article, "Applications of Thevenin's Theorem," (*EE, Mar '45, pp. 103–5*) will do much to lighten the work of network calculation for those who do not already make use of the theorem, particularly as the well-chosen examples not only extend into noncommunication fields but emphasize the use of the theorem in network synthesis rather than analysis alone, with which latter many of us are prone to associate it.

It follows that Thevenin's theorem has a corollary, Norton's theorem, which, together with its proof, I have put in the same phraseology as that of Mr. Richter's article. While the corollary appears to be no more useful, and in many cases less so than the theorem itself, it may be of some interest. The corollary and its proof follow:

Corollary. The voltage across any single branch of a network consisting of any number of impedances and voltage sources can be found in the following manner: short-circuit the branch under consideration, and determine the short-circuit current; then consider all voltage sources as short-circuited or—if they have internal impedance—replaced by an impedance equal to the internal impedance of them, and calculate the impedance of the network when measured across the branch in question (with the short circuit removed). The voltage that will appear across the branch under consideration will be the short-circuit current multiplied by this impedance.

Proof of Corollary. Assume that in a network consisting of linear impedances, $z_1, z_2, \ldots z_n$, and voltage sources, $E_1, E_2, \ldots E_m$, it is desired to determine the voltage drop across z_k. Upon reducing the impedance of this branch to zero (by means of a zero-impedance jumper) a short-circuit current I_{kz} will result and the voltage e_k, of course, will be zero. Now suppose that in series with the zero-impedance jumper is connected a current source of such sign and magnitude as to reduce the original branch current i_k (and con-

sequently e_a) to zero. This obviously will not change anything from the short-circuit condition of the branch z_a, as far as the rest of the network is concerned. There is now a network with no short-circuited branches but with a new current source equal to I_{ba} introduced into the network. The voltage distribution in the network now is determined by the original m voltage sources plus the new current I_{ba}. But under the new condition the branch voltage across z_a is zero, and, according to the superposition principle, the introduction of I_{ba}, with all the voltage sources short-circuited, must be such as to cancel exactly the original current in (and voltage across) the branch z_a. The voltage originally across z_a therefore must be equal to a voltage that would exist, if all original voltage sources were short-circuited, but a current source equal to but opposite in polarity to I_{ba} had been introduced across the branch z_a. This proves the corollary to Thevenin's theorem.

Both the article and the foregoing remarks might have been a little more rigorous with provision in the network for current sources and their internal shunt impedances, but these cases (such as pentode amplifier circuits) are easily included.

SIDNEY B. WILLIAMS (A '37)

(Assistant project engineer, propeller division, Curtiss-Wright Corporation, Caldwell, N. J.

NEW BOOKS

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question

Metallography of Magnesium and Its Alloys. A translation from the German by the technical staffs of F. A. Hughes and Company Ltd. and Magnesium Elektron Ltd. of "Metallographie des Magnesiums und seiner technischen Legierungen." By W. Bulian and E. Fahrenhorst. F. A. Hughes and Company, Ltd. London, England, 1944. 117 pages, illustrated, 9½ by 6 inches, cloth, 15s. (ESL.)

This, the first book devoted solely to the metallography of magnesium and its alloys, appeared in Germany in 1942. The translation is by the staffs of British producers of the metal. The book opens with a short description of polishing and etching technique, which is followed by a description of the alloy constituents and impurities that are discernible in micrographs. The remainder of the book discusses 225 micrographs that are presented and the information that they reveal as to the nature of the alloy, its pretreatment, and its faults. To the references in the original edition, the translators have added a list of non-German references.

MacRae's Blue Book and Hendrick's Commercial Register, 52d annual edition 1944–45. MacRae's Blue Book Company, Chicago, Ill., and New York, N. Y., 1945. 3,736 pages, illustrated, 11 by 8 inches, cloth, $15. (ESL.)

The major part of this standard annual buyers' guide is a comprehensive alphabetical list of products with the manufacturers arranged alphabetically under each product. In some of the larger classifications there is both a geographical and alphabetical arrangement. Preceding this section is a complete alphabetical file of manufacturers giving full addresses, capital ratings, and local distributors. A 300-page list of trade names is included at the back of the volume.

Annual Report on the Progress of Rubber Technology, volume 7, 1943. Edited by T. J. Drakeley, published by W. Heffer and Sons, Ltd., Cambridge, England, for the Institution of the Rubber Industry, London, England, 1944. 129 pages, 9½ by 7 inches, paper, 12s.6d. (4s.6d. to members). (ESL.)

This annual contains excellent reviews of developments in various fields: production, chemistry and physics, synthetic rubber, compounding, fibers and textiles, vulcanized rubber, tires, belting, hose and tubing, cables and electrical insulation, footwear, mechanical goods, flooring, surgical goods, solvents, sponge rubber, hard rubber, works processes, and machinery. Each report includes a bibliography. Name and subject indexes are provided.

Theory and Applications of Electron Tubes. By H. J. Reich. Second edition. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1944. 716 pages, illustrated, 9 by 5¾ inches, cloth, $5. (ESL.)

This book is intended to give, in one volume, a sufficiently thorough grounding in the fundamentals of electron tubes and associated currents to enable the student to apply these tubes to the solution of new problems. The basic principles are presented, and special attention is given to their application to industrial electronics, power control, electrical measurements, and other fields of use. The new edition has been brought up to date.

Metallography and Heat-Treatment of Steel. Volume 3, Ferrous Metallurgy (Mineral Industries Series.) By E. J. Teichert. Second edition. McGraw-Hill Book Company, New York, N. Y., and London, England, 1944. 577 pages, illustrated, 8½ by 5¼ inches, cloth, $5. (ESL.)

The text on ferrous metallurgy, of which this is the final volume, is intended especially for those employed in the steel industry who wish to acquire a working knowledge of fundamental principles. In this volume the physical metallurgy of the iron and steel alloys, metallography, and heat treatment are considered. The work is well adapted for private study.

Readjustment of Man Power in Industry During the Transition From War to Peace. (Research Report Series 71.) By H. Baker. Princeton University, Princeton, N. J., 1944. 112 pages, tables, 9¼ by 6 inches, paper, $1.25. (ESL.)

The material presented constitutes an analysis of the policies and programs presently under consideration by industry for absorbing the returning man power after the war. The results of a large number of discussions with industrial, union, and government executives are grouped under three headings: organization and extent of company planning; transitional adjustments in the present labor force; employment and re-employment of veterans.

Symposium on Plastics. American Society for Testing Materials, Philadelphia, Pa., 1944. 200 pages, illustrated, 9 by 6 inches, paper, $1.75; cloth, $2. (ESL.)

Of the 16 papers by authorities in the field presented in this publication, the first eight deal with such topics as the heat resistance of laminated plastics, diffusion of water through plastics, and the behavior of plastics under certain conditions and test methods. The rest of the papers are grouped together as a summary of properties, uses, and salient features of the following families of plastics: phenolics, polystyrenes, urea and melamine, allyl, vinyl, cellulose, methacrylate, and nylon plastics.

High-Speed Combustion Engines. By P. M. Heldt (12th edition of "The Gasoline Motor") published by the author, Nyack, N. Y., 1944. 776 pages, illustrated 8½ by 5¼ inches, cloth, $7.50. (ESL.)

This standard work, now in its 12th edition, provides a comprehensive reference book for engineers as well as a textbook for students. The separate working parts of the high-speed combustion engine are covered in detail, including chapters on the carburetor and ignition equipment not previously included. Theory, design principles, production practice, and operation all are given consideration, and two chapters are devoted to engine tests and the thermodynamic laws.

Vibration Analysis. By N. O. Myklestad. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1944. 303 pages, illustrated, 8½ by 5¼ inches, cloth, $3.50. (ESL.)

The first five chapters are written from the textbook point of view to provide an understanding of the various phases of the phenomenon of vibration. Important topics covered are undamped and damped vibrations of systems of one degree of freedom and vibrations of systems with more than one degree of freedom. The last chapter deals with applications to important practical problems, chiefly in the aeronautical field.

The Industrial Supervisor. By J. M. Amis and T. C. Sutton. Ronald Press Company, New York, N. Y., 1944. 243 pages, illustrated, 8¼ by 5¼ inches, cloth, $3. (ESL.)

The opening chapters discuss general supervisory responsibilities and the general qualifications of a supervisor. Succeeding chapters deal with the many specific responsibilities of the supervisor from a practical viewpoint, provide necessary technical information, and show how particular qualifications may be gained or improved. The book is intended for home study, industrial training departments, or conference discussions by small groups.

Principles of Physics, volume 1, Mechanics, Heat, and Sound. By F. W. Sears. Addison-Wesley Press, Cambridge 42, Mass., 1944. 526 pages, illustrated, 9¼ by 6 inches, cloth, $5. (ESL.)

This text is based on the first course in

physics given at the Massachusetts Institute of Technology. It covers the subjects: mechanics, heat, and sound, which form the first year of the two-year course, and is given to students who are concurrently given a course in analytical geometry and calculus. The emphasis throughout is on physical principles, and the calculus is used freely. Numerous problems are provided.

Engineering Mathematics. By H. Sohon. D. Van Nostrand Company, Inc., New York, N. Y., 1944. 278 pages, illustrated, 9¼ by 6 inches, cloth, $3.50. (ESL.)

This book is intended for engineering students who have completed the study of the elementary calculus and for graduate engineers seeking to bolster their present knowledge of mathematics. Determinants and matrix theory, Fourier series, differential equations, vector algebra, and vector calculus are important subjects dealt with in the text. The theory and solution of algebraic equations in general are effectively covered.

Milling Machine Operations. By L. E. King. The Macmillan Company, New York, N. Y., 1944. 123 pages, illustrated, 8½ by 5½ inches, paper, $1.75. (ESL.)

This guide for apprentices and students in shop courses is intended to teach the performance of various milling-machine operations.

Engineering Contracts and Specifications. By R. W. Abbett. John Wiley and Sons, Inc., New York, N. Y.; Chapman and Hall, Ltd., London, England, 1945. 188 pages, illustrated, 8¾ by 5¾ inches, cloth, $2.25. (ESL.)

Upon the basis of experience both as a teacher and a contractor, the author has attempted to present in compact form some of the legal and business aspects of the engineering profession. The legal considerations in construction work are summarized, the types of contracts are described, and the essentials of each type are discussed. Examples of each type are shown. Bidding procedure is described and a chapter is devoted to specification writing.

Theory of X-Ray Diffraction in Crystals. By W. H. Zachariasen. John Wiley and Sons, Inc., New York, N. Y.; Chapman and Hall, London, England, 1945. 255 pages, illustrated, 8½ by 5½ inches, cloth, $4. (ESL.)

This book aims to give a logical presentation of both the theory of crystal symmetry and the theory of X-ray diffraction in crystals.

Intermediate Aerodynamics. By R. W. Truitt. Pitman Publishing Corporation, New York, N. Y., and Chicago, Ill., 1944. 227 pages, illustrated, 9¼ by 6 inches, cloth, $3.75. (ESL.)

The important elements necessary for the accurate application of aerodynamics are presented with sufficient descriptive material to emphasize their practical use. Thorough mathematical explanations are given for problems relating to the airfoil, drag, stability, load factors, propellers, slots, and flaps. A glossary of aeronautical terms is appended.

Plastics in the World of Tomorrow. By B. W. Leyson. E. P. Dutton and Company, New York, N. Y., 1944. 184 pages, illustrated, 8¼ by 5½ inches, cloth, $2.50. (ESL.)

A general survey of the subject intended for nontechnical readers is provided in this book. The various plastics are described, their uses enumerated, and future possibilities discussed.

Enamel Bibliography and Abstracts, 1928 to 1939. Compiled by E. H. McClelland; edited and published by the American Ceramic Society, Columbus, Ohio, 1944. 352 pages, tables 11 by 7¾ inches, cloth, $5. (ESL.)

This compilation provides full references to the literature published during the period, 1928–39, with excellent abstracts. The arrangement is by authors, with an extensive detailed subject index. The bibliography is a model for such works.

Chambers's Technical Dictionary. Edited by C. F. Tweney and L. E. C. Hughes. Revised edition with supplements. The Macmillan Company, New York, N. Y., 1944. 975 pages, illustrated, 8¼ by 5¼ inches, cloth, $6. (ESL.)

This dictionary defines terms used in pure and applied science, in engineering and construction, in manufacturing, and in the skilled trades. The new edition has been revised and a supplementary list of nearly 1,000 definitions added.

Airport Engineering. By H. O. Sharp, G. R. Shaw, and J. A. Dunlop. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1944. 150 pages, illustrated, 11¼ by 8½ inches, cloth, $5. (ESL.)

This undergraduate textbook presents concisely the problems that confront the airport builder. After a brief discussion of airport size and site, planning and preliminary surveys are considered. Problems of grading, drainage, soil stabilization, and paving then are treated. Finally, lighting, buildings, and construction and maintenance equipment are presented.

Comfortization of Aircraft. By A. A. Arnhym. Pitman Publishing Corporation, New York, N. Y., and Chicago, Ill., 1944. 347 pages, illustrated, 9¼ by 6 inches, cloth, $7.50. (ESL.)

Looking to the future, designers and others associated with the airplane industry and air transport are concerned with passenger comfort and conveyance. The author has assembled technical data, calculations, information, and illustrations useful in eliminating the discomforts of flying. He outlines the various important phases, and gives a detailed analysis of air supply, heat supply, soundproofing, seating, berthing, catering, and the like. Procedures and methods are included for incorporating, specifying, selecting, and servicing comfort equipment.

General Meteorology (published formerly under the title, "Synoptic and Aeronautical Meteorology"). By H. R. Byers. McGraw-Hill Book Company, New York, N. Y., and London, England, 1944. 645 pages, illustrated, 9 by 5½ inches, cloth, $5. (ESL.)

This book is designed as a general text embodying the fundamentals as well as the modern development in synoptic meteorology, including recent advances in the field such as: isentropic analysis and new forecasting uses of upper-air pressure charts. The last five chapters of the book cover material of particular importance in aeronautics. An appendix contains practical aids for the student and meteorologist.

Helicopter Design Theory. By A. A. Nikolsky. Princeton University Press, Princeton, N. J., 1944. 228 pages, illustrated, 9 by 6 inches, paper, $3. (ESL.)

This volume presents at series of lectures given at Princeton University in the spring of 1944 to a group of engineers representing the Army and Navy air services and various aircraft manufacturers. The treatment is theoretical and mathematical and, of necessity, tentative, as theory in this field is still in an unstable state.

Heating Ventilating Air Conditioning Guide. 23d edition. American Society of Heating and Ventilating Engineers, New York, N. Y., 1945. 1,216 pages. 6 by 9 inches, $5.

This edition contains 48 chapters of technical data and information grouped under the general subdivisions, Principles; Heating and Cooling Load Calculations; Combustion and Consumption of Fuels; Steam and Hot Water Heating; Air Heating, Cooling and Conditioning; Automatic Controls, Instruments and Motors; Special Applications, and Miscellaneous. Many chapters have been rewritten or revised, and new material has been added to the chapters on Terminology as well as Abbreviations, Symbols, Standards; and conversion equations and constants listed have been corrected to agree with latest accepted values of the National Bureau of Standards. This edition contains 808 pages of technical data; 344 pages of equipment data and the Roll of Membership of the Society. A 15-page index, a single-page quick-reference table of contents, and a brief summary of chapter contents under each chapter heading provide easy reference to subjects treated in this book.

PAMPHLETS • • • •

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Patent Digest Service (Resins, Rubbers, Plastics), volume 1, issue 1. Interscience Publishers, Inc., New York 3, N. Y.

War Production and V-E Day, Second Report. By the Director of War Mobilization and Reconversion, Washington, D. C., 46 pages.

Steam Power Plant Planning Guide (10,000 to 60,000 kw). Westinghouse Electric and Manufacturing Company, Lester Branch Post Office, Philadelphia 13, Pa.

The Story of the Diesel. The Diesel Engine Manufacturers Association, Chicago 2, Ill., 32 pages.

Panoramic Reception (From One Ham to Another). Panoramic Radio Corporation, New York, N. Y. 31 pages.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

A Comparison of the Amplitude-Modulation, Frequency-Modulation, and Single-Side-Band Systems for Power-Line Carrier Transmission

R. C. CHEEK
ASSOCIATE AIEE

MANY utility engineers interested in increasing the applications of power-line carrier on their systems are confronted today with the difficult problem of finding space for additional channels in an already crowded carrier spectrum. This is a problem, not only for large utilities which have extensive carrier systems of their own, but also for smaller companies interconnected into large groups in which the total number of carrier installations is large.

Other problems that arise in some power-line carrier applications are the high attenuation of some long-haul communication and telemetering circuits, particularly those which include several by-pass points, and the high interference and noise levels that exist on some lines.

In general, increasing the power of ordinary amplitude-modulation equipment does not provide a satisfactory solution to these problems. This fact has led to a consideration of the possibilities in the power-line carrier field of two systems of transmission fundamentally different from the amplitude-modulation system, namely, the frequency-modulation system and the single-side-band system.

The ability of a frequency-modulation power-line carrier system to provide gains in signal-to-noise ratio over the amplitude-modulation system with certain types of noise has been reported in a previous paper.[1] The channel width which must be provided for a frequency-modulation system in order to obtain appreciable gains in this respect was not clearly brought out, however. It is the purpose of the present paper to consider more fully this limitation of the frequency-modulation system for power-line carrier work, and to furnish a comparison of the amplitude-modulation, frequency-modulation, and single-side-band systems on the basis of their channel-width requirements, their ability to work through attenuation, and their susceptibility to interference and noise. Since the amplitude-modulation system is used in this paper as a basis of comparison for the other two systems, it will be considered first.

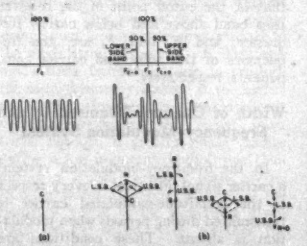

Figure 1. Amplitude-modulation system

(a). Unmodulated conditions, in spectrum, wave, and vector representation
(b). Complete modulation

Width of Channel Required by the Amplitude-Modulation System

Conditions are shown in Figure 1a for the amplitude-modulation system when no modulation is present, that is, when there is no speech or telemetering impulse on the channel. The only component in the frequency spectrum is the carrier, a constant-amplitude single-frequency sine wave, which is shown in vector form as a single vector of constant length. This vector is assumed to be rotating counter-clockwise at carrier frequency. Its length can be taken as unity or 100 per cent.

Conditions for 100-per-cent amplitude modulation of the carrier wave by a sinusoidal audio tone are shown for comparison in Figure 1b. In addition to the carrier-frequency wave of 100-per-cent amplitude, two additional high-frequency waves are introduced into the frequency spectrum, one of a frequency equal to carrier frequency plus modulating frequency, and one of frequency equal to carrier frequency minus modulating frequency. The amplitude (voltage) of each of these additional components, which are called the side-band components, is 50 per cent of the carrier amplitude. The power in each side-band component therefore is 25 per cent of the carrier power. This gives a total average power during complete modulation of 1.5 times the unmodulated carrier power. This power is the average of the variations in total transmitted power as the carrier and side-band components combine to give a wave whose power varies between the limits of zero and four times the unmodulated carrier power during an audio cycle.

A vector representation is given in Figure 1b of the way in which the side-band components combine with each other and with the carrier component to produce a resultant whose amplitude varies between zero and twice carrier amplitude and whose frequency is always carrier frequency. The vector diagrams are drawn for successive intervals of time during an audio cycle. The vectors representing the upper and lower side-band components revolve about the carrier vector in opposite directions at audio frequency, because their frequencies are carrier frequency plus audio frequency and carrier frequency minus audio frequency, respectively. The two side-band vectors are always of just the proper phase to produce a resultant which directly aids or opposes the carrier vector.

In the foregoing discussion, modulation by a single audio frequency was assumed. This produced one pair of side-band components. If more than one audio frequency were present, a pair of side-band components for each, of frequency equal to carrier plus audio frequency and carrier minus audio frequency, would be produced. In such a case the sum of the amplitudes of the upper side-band components would equal 50 per cent of the carrier amplitude, and the sum of the lower side-band components would equal

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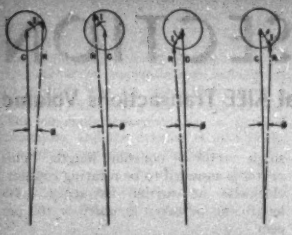

Figure 2. Amplitude and phase modulation of a carrier by an interfering wave

50 per cent of the carrier amplitude for complete modulation.

In the amplitude-modulation system the carrier and all side-band components are transmitted, and an amplitude-modulation receiver must accept a frequency band sufficiently wide to accommodate the lowest and highest side-band components produced. The channel width required is therefore twice the frequency of the highest audio frequency to be transmitted. In power-line carrier work this normally means a band of six kilocycles to accomodate speech frequencies and audio tones as high as three kilocycles.

Effects of Interference and Noise on an Amplitude-Modulated Signal

In the amplitude-modulation system, the receiver responds only to changes in the amplitude of the carrier; changes in the phase or slight changes in the frequency of the carrier produce no audible output from the receiver. Interference with an amplitude-modulated signal occurs when an undesired wave is passed by the tuned circuits of the receiver (which must accept all frequencies in a six-kilocycle band in the system under discussion) and adds to the carrier wave in much the same manner as the desired side-band components add to it, producing variations in its amplitude. If the undesired signal is another carrier wave, the familiar beat-note type of interference is the result. The frequency of the audio output of the receiver for this type of interference is the difference between the frequencies of the carrier and the interfering wave. The amplitude of the audio output is the same for all interfering waves of equal amplitude applied to the detector, whether their frequency is close to that of the desired carrier or close to the edge of the band accepted by the receiver.

Vector diagrams showing the effect of interference on an amplitude-modulated carrier are given in Figure 2, in which the amplitude of the interfering wave is assumed to be ten per cent of the amplitude of the desired carrier. Assuming that no side-band components are present, that is, that the carrier is not intentionally being modulated, the carrier vector is again a vector of constant length, rotating at carrier frequency. The vector representing the interfering wave adds to the carrier vector and revolves about it at a frequency equal to the difference in frequency between the two. The resultant vector varies in amplitude and phase at this difference frequency. The amplitude variations are equivalent to ten-per-cent modulation of the carrier amplitude, and the receiver detects them as such.

The foregoing discussion was based on interference from a single-frequency wave. Random noise consists of a large number of such waves of all frequencies, distributed throughout the band accepted by the receiver. The effective noise voltage output of the receiver is the effective value of the noise produced by all the random noise components accepted by the receiver. Assuming that noise components of all frequencies are present, and that they have equal amplitudes, the rms noise output of an amplitude-modulation receiver is

$$E_{rms} = \sqrt{\int_{-f_{max}}^{f_{max}} k^2 d(F_n - F_c)} = k\sqrt{2f_{max}} \quad (1)$$

where k represents the amplitude of the noise produced by each individual noise component, f_{max} is the highest audio frequency to be transmitted by the system, that is, the cutoff point of the receiver pass band above and below carrier frequency, and F_n and F_c are the frequencies of the noise and carrier components, respectively.

Width of Channel Required by the Frequency-Modulation System

In the frequency-modulation system[3] a carrier signal, identical in every respect to the amplitude-modulated carrier, is transmitted during periods when modulation is absent. These conditions are shown in Figure 3a. The only quantity transmitted is a constant-amplitude single-frequency sine wave, represented by a single vector of constant length.

When modulation is present the conditions shown in Figure 3b are obtained in a particular frequency-modulation system. The transmitted wave has the same amplitude as the original carrier, but its frequency varies above and below the original carrier frequency. This variation in frequency takes place at a rate corresponding to the audio frequency being transmitted. It is caused by the presence of side-band components, as in the amplitude-modulation system. However, several important differences exist. Instead of a single pair of side-band components for a single modulating frequency, as in amplitude-modulation, an infinite number of side-band pairs is produced in frequency modulation. These side-band pairs are spaced in the spectrum above and below carrier frequency at multiples of the audio frequency. The first side-band pair occurs at carrier plus audio frequency and carrier minus audio frequency, as in amplitude modulation. The second pair occurs at carrier plus and minus twice audio frequency, the third at carrier plus and minus three times audio frequency, and so on. Although there are an infinite number of side-band pairs in a frequency-modulated signal, the amplitude of each pair is generally different, and at a certain distance in each direction from carrier frequency the amplitudes of higher- and lower-frequency side-band components become negligible.

Another important difference between frequency modulation and amplitude modulation is that in frequency modulation the amplitude of the carrier-frequency component is always reduced during modulation, and the vector representing it changes in length accordingly. However, the resultant obtained by adding the new carrier vector and the side-band vectors is always in true frequency modulation a vector of length equal to the original length of the vector representing the carrier. The intelligence is transmitted, not by a change in the amplitude of the resultant vector, but by a continuous oscillation in its phase position. This oscillation in the phase position of the resultant vector introduces a modulation of the frequency, because during the process of a change in phase a change takes place in the speed of rotation of the vector, which of course means a change in frequency. The frequency deviation from normal at any instant is proportional to the rate at which the phase of the resultant vector is changing at that instant.

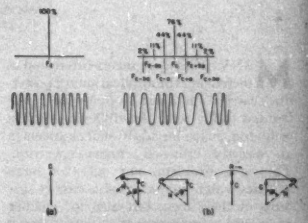

Figure 3. Frequency-modulation system

(a). Unmodulated conditions, in spectrum, wave, and vector representation

(b). Modulation with unity deviation ratio

The ratio of the maximum resultant frequency deviation to the highest audio frequency to be transmitted in a frequency-modulation system is called the deviation ratio. The conditions shown in Figure 3b are those obtained with a maximum carrier-frequency deviation of three kilocycles above and below normal with a modulating frequency of three kilocycles. If three kilocycles is the highest

audio frequency to be transmitted in this system, as is assumed to be the case in all systems considered in this discussion, the deviation ratio of the system is unity. A system with unity deviation ratio has been chosen for illustration because, as will be shown later, it is only with a deviation ratio of at least unity that the frequency-modulation system offers appreciable gains in signal-to-noise ratio over amplitude modulation.

The vector diagrams of Figure 3b show at successive intervals of time how with unity deviation ratio the resultants of each pair of side-band vectors add to the carrier vector to maintain the amplitude but to produce a change in the phase of the transmitted wave. The two vectors representing the first side-band pair revolve about the carrier vector in opposite directions at audio frequency. Their resultant is always of such a phase as to add in quadrature with the carrier vector. The vectors representing the second side-band pair revolve about the resultant of the first side-band pair at twice the audio frequency, producing by themselves a resultant always in phase with the carrier vector. The vectors of the third side-band pair revolve about the resultant of the second side-band pair at three times the audio frequency, producing by themselves a resultant always in quadrature with the carrier vector. There are successively higher and lower side-band pairs, but they are small and their resultants are not shown. The total effect of all the vectors is to produce a resultant vector whose length is always that of the vector representing the original carrier, but whose phase varies in accordance with the transmitted audio frequency. This phase oscillation produces an oscillation in the frequency of the transmitted wave.

It can be seen in Figure 3b that, although the frequency swing of the resultant wave is only three kilocycles above and below carrier frequency, the side-band components that must be transmitted in order to obtain this frequency swing actually occupy a band width greater than six kilocycles. According to Hund,[2] good engineering practice requires that the side-band components in a band 50 per cent greater than the maximum resultant frequency swing above and below normal carrier frequency be transmitted, that is, all side-band components in a band of width $1.5 \times 2\Delta F$, where ΔF is the maximum frequency deviation from normal. Narrowing the transmitted or received band width to less than this figure will introduce excessive audio distortion into the channel.

Suppose, for example, an attempt were made in the system under consideration to reduce the channel width occupied by the transmitted signal by transmitting only those side-band components in a frequency band three kilocycles above and below carrier frequency. For modulation by any audio frequency from three kilocycles down to 1.5 kilocycles, the carrier and only a single pair of side-band components would be transmitted. At successively lower frequencies in this range, the amplitude of the carrier component becomes successively less, the amplitudes of the suppressed side-band components become greater, and the distortion of the apparent swing of the resultant signal increases. The distortion is greatest just below the point at which the second side-band pair comes within the transmitted band of frequencies, that is, at a modulating frequency of 1.5 kilocycles. The resultant frequency swing, as it appears to a discriminator with center frequency tuned to carrier frequency, is shown in Figure 4 for several modulating frequencies between 1.5 and 3 kilocycles. The curves of Figure 4 were plotted from relations derived in the appendix.

Effects of Interference and Noise on a Frequency-Modulated Signal

The frequency swing of a frequency-modulated signal above and below normal frequency depends upon two factors: the loudness of the modulating signal, and the frequency swing the system is designed to have for a signal of that loudness. The frequency swing in a given frequency-modulation system is the same for any audio frequency of a given loudness. This means that the phase swing must be inversely proportional to the modulating frequency. If the lower modulating frequencies are to produce the same frequency change as the higher modulating frequencies, the resultant vector representing the signal must travel through a greater phase change during a low-frequency audio cycle than during a higher-frequency audio cycle. In other words, the speed of swing of the resultant vector is the same at a given point on the audio cycle, whether the audio frequency is high or low. The resultant vector has a longer time to change in phase during a low-frequency audio cycle; so the actual phase swing is greater than for a higher-frequency audio cycle. This fact is important to an understanding of the way in which frequency modulation can provide gains in signal-to-noise ratio over amplitude modulation.

The deviation ratio in frequency modulation expresses in radians the maximum phase swing when the signal is modulated by a wave of maximum loudness and of the highest audio frequency the system is intended to transmit. In the system under consideration, which has unity-deviation ratio, the phase swing is one radian when a three-kilocycle tone of maximum loudness is being transmitted. This phase swing varies inversely with the audio frequency if the audio amplitude is kept constant and becomes enormous with very low modulating frequencies.

Consider the effect of adding to the unmodulated frequency-modulation carrier the same interfering signal assumed in the discussion of amplitude modulation in Figure 2. If the interfering wave has ten per cent of the amplitude of the desired carrier and has a frequency three kilocycles away from carrier frequency, the vector representing it will revolve around the carrier vector as before, producing a resultant whose amplitude varies ten per cent above and below normal amplitude and whose phase oscillates with a maximum swing of 5.7 degrees or 0.1 radian. Amplitude limiters in the frequency-modulation receiver remove the amplitude variations, but the receiver responds to the phase variations. The phase swing is one tenth of the swing produced when the system is modulated by a three-kilocycle tone of maximum loudness; therefore the interfering signal causes the same amount of interference it caused to the amplitude-modulation carrier.

If the interfering signal is removed only 1.5 kilocycles in frequency from the carrier, however, conditions are somewhat different. Assuming again that the amplitude of the interfering wave is ten per cent of normal carrier amplitude, the same 0.1-radian phase oscillation occurs,

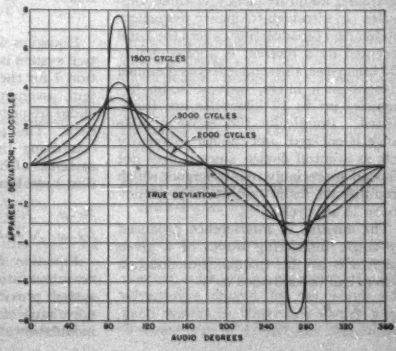

Figure 4. Distortion of a frequency-modulated signal when all except the first pair of side-band components are suppressed

Unity deviation ratio, highest audio frequency three kilocycles

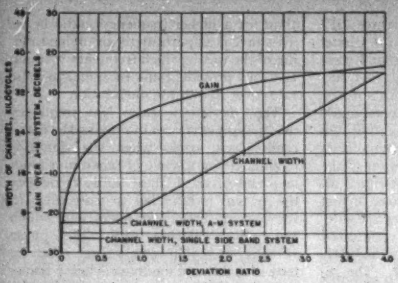

Figure 5. Decibel gain of frequency modulation over amplitude modulation and channel width required by frequency-modulation system as deviation ratio is increased

Maximum audio frequency three kilocycles

this time at a frequency of 1.5 kilocycles. This swing is only $^1/_{20}$ of the phase swing for a desired 1.5-kilocycle modulation of maximum loudness. The result is that, although the amplitude of the interfering wave is the same as before, the amount of audio output it causes is only half as much. As the interfering signal gets closer and closer in frequency to the carrier, the audio output it produces becomes less and less, reaching zero at carrier frequency.

It has been shown that in order to obtain reasonably distortion-free reproduction of the signal, the receiver in this system will have to accept a band of frequencies greater than three kilocycles above and below carrier frequency. Interfering waves in this band removed more than three kilocycles from the carrier will cause more interference in the frequency-modulation receiver than they would cause in the corresponding amplitude-modulation receiver, even if the latter were required to accept such frequencies. Actually the radio-frequency circuits in an amplitude-modulation receiver normally are designed to pass a band of width equal to twice the maximum audio frequency, or six kilocycles in this case. The same effect could be obtained in the frequency-modulation receiver under consideration by passing the required band of frequencies in the radio-frequency circuits but designing the audio circuits so that they cut off sharply at the maximum audio frequency of three kilocycles. In ultrahigh-frequency frequency-modulation broadcasting, where the band accepted by a receiver is approximately 225 kilocycles, the same effect is obtained without such filters, because audio frequencies up to 15 kilocycles are transmitted. Practically the entire audible range is covered, and the ear inherently acts as a cutoff device, since it does not respond appreciably to interference which produces an audio output of frequency above 15 kilocycles.[3]

The amount of interference produced by single interfering waves of a given amplitude in the frequency-modulation system can be expressed as

$$E_4 = k\frac{F_i - F_c}{\Delta F} \qquad (2)$$

in which $F_i - F_c$ is the difference between the interfering frequency and the carrier frequency, and k is the interference produced when this difference is equal to ΔF, the maximum deviation of frequency of the system. The factor k in equation 2 is the same as the factor k which appears in equation 1 for the amplitude-modulation system, if it is assumed that the frequency ΔF is in the audible range and is passed by the audio circuits of the receiver.

The effect of random noise upon a frequency-modulation signal can be found by integrating to determine the rms noise output, as before. Assuming that a band width of $1.5 \times 2\Delta F$ is passed by the frequency-modulation receiver, we have

$$E_{rms} = \sqrt{\int_{-1.5\Delta F}^{1.5\Delta F} k^2\left[\frac{F_n - F_c}{\Delta F}\right]^2 d(F_n - F_c)} = 1.5k\sqrt{\Delta F} \qquad (3)$$

if it is assumed that ΔF is within the range of audible frequencies and that no low-pass filter is provided in the audio circuits of the receiver. If such a filter is provided, the maximum gain in signal-to-noise ratio is obtained when its cutoff frequency is f_{max}, the highest audio frequency to be handled by the system. The limits of integration in equation 3 in this case become $-f_{max}$ and f_{max}, and we have

$$E_{rms} = \frac{kf_{max}\sqrt{2f_{max}}}{\sqrt{3}\Delta F} \qquad (4)$$

Equation 4 for the frequency-modulation system is exactly equivalent to equation 1 for the amplitude-modulation system, assuming that the same maximum audio frequency is to be transmitted by each. This provides a basis for directly comparing the performance of the two systems. Dividing equation 4 by equation 1, we have

$$\frac{E_{F-M}}{E_{A-M}} = \frac{f_{max}}{\sqrt{3}\Delta F} \qquad (5)$$

Equation 5 shows that with unity-deviation ratio, the frequency-modulation system provides a gain in rms signal-to-noise ratio of 4.8 decibels over amplitude modulation. Larger-deviation ratios provide larger gains, but these gains can be obtained only at the expense of channel width. Figure 5 shows, for systems in which the maximum audio frequency is three kilocycles, a curve of the decibel gain afforded by the frequency-modulation system as the deviation ratio is increased. A curve giving the channel width required by the system as the deviation ratio is increased is also shown for comparison. The latter curve is based on the requirement that the channel width be $1.5 \times 2\Delta F$ for reasonably distortion-free reproduction.

The Single-Side-Band System

In the amplitude-modulation system, the carrier-frequency component of the signal is unchanged during modulation, as shown in Figure 1. Modulation merely introduces additional components, which act upon the carrier in such a way that the amplitude of the resultant signal varies above and below carrier amplitude. It can be seen from the vector diagrams of Figure 1b that it would be possible to communicate with one of the side-band components suppressed. The remaining component still would produce amplitude variations in the resultant signal at the modulating frequency, and these variations could be detected by an ordinary amplitude-modulation receiver. It is possible to go a step further and suppress the carrier itself as well as the components of one of the side bands. If this is done in a low-power stage of an amplitude-modulation transmitter, the entire power capability of the transmitter can be used to amplify and transmit the components of a single side band. The carrier-frequency component, upon which the side-band components act to produce amplitude variations, can be supplied by a small oscillator at the receiving end of the channel; thus, instead of using a comparatively large amount of power at the transmitting end to generate a constant-frequency constant-amplitude sine wave, which contains no intelligence, and subjecting it to all the attenuation and losses involved in transmitting it to the receiving end of the channel, it is possible to produce the equivalent of this wave with very little power at the receiving point. The power which ordinarily is used at the sending end to transmit the carrier component then can be used to transmit intelligence-bearing components of a single side band. In the remainder of this paper, the single-side-band system referred to is the type in which the carrier as well as one of the side bands is suppressed.

The conditions for no modulation in the single-side-band system are shown in Figure 6a. The frequency spectrum contains no components of any frequency under these conditions, and the constant-frequency constant-amplitude carrier common to the amplitude-modulation

and frequency-modulation systems is absent.

When modulation is present, again assuming modulation by a single audio frequency, a single component of frequency appears in the spectrum, as shown in Figure 6b. This quantity is a pure sine wave, of constant amplitude, and of constant frequency equal to nominal carrier frequency plus audio frequency, assuming that the upper side-band component is being transmitted. Actually, either the upper or the lower side-band component could be used. No carrier-frequency component is transmitted under any conditions.

The vector diagrams of Figure 6b represent conditions at the receiving end of a single-side-band channel when modulation is present. The locally generated carrier wave is shown as a dotted vector, to which the incoming side-band vector is added. The frequency of the side-band wave differs from the locally generated carrier frequency; therefore the vector representing it revolves about the carrier vector. This variation takes place at audio frequency, and the resultant vector varies in amplitude at the audio frequency. The resultant wave, produced by adding the local carrier and the received side-band wave, is a wave very similar to that which would have been obtained had the carrier and both side-band components been transmitted from the sending end. This resultant wave can be applied to an ordinary amplitude-modulation detector and rectified in the usual manner.

The width of the channel required by the single-side-band system is exactly half that required by the amplitude-modulation system. In other words, the space in the spectrum occupied by a single-side-band transmitter and the band of frequencies which must be accepted by the receiver are equal to the maximum audio frequency to be transmitted, or three kilocycles for ordinary power-line carrier work.

Gains in Signal-to-Noise Ratio With the Single-Side-Band System

A single-side-band receiver must accept only half the band width required in an amplitude-modulation receiver. The lower limit of the integral of equation 1 is zero for the single-side-band system, and we have

$$E_{rms} = \sqrt{\int_0^{f_{max}} k^2 d(F_n - F_c)} = k\sqrt{f_{max}} \quad (6)$$

Halving the band width therefore eliminates half of the noise power and provides an immediate gain of three decibels for the single-side-band system. Other gains can be realized, depending upon the characteristics of the transmitter used to amplify the single-side-band signal.

In the amplitude-modulation system the average power transmitted during complete modulation is 1.5 times the unmodulated carrier power. The extra power required during modulation can be supplied in several different ways. In one system, the output stage of the transmitter is capable of handling only the normal carrier power, and the additional 50 per cent is supplied by power-type modulator tubes. In another system, the output stage of the transmitter operates at a relatively low efficiency during periods of no modulation. The modulator supplies no appreciable power but acts to change the efficiency of the transmitter during modulation, increasing the average output by 50 per cent. In both cases, the 1.5 times normal power during modulation is the average power transmitted as the instantaneous power varies between the limits of zero and four times normal during the audio cycle, and an amplitude-modulation transmitter of the efficiency-modulated type must be able to produce this four times normal power at its peak efficiency, which it reaches for an instant during each audio cycle.

When an amplitude-modulation transmitter of the efficiency-modulated type is used to amplify a single-side-band component, it can operate at peak efficiency throughout the audio cycle, because the signal is a constant-amplitude radio-frequency wave without the peaks and "troughs" of an amplitude-modulation signal. The amplitude of the single-side-band component transmitted therefore is twice the amplitude of the carrier which is transmitted by the same equipment in the amplitude-modulation system. This signal, added to the locally generated

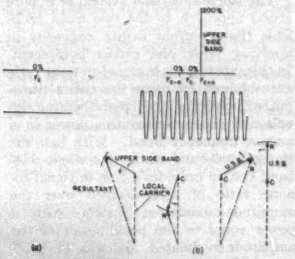

Figure 6. Single-side-band system, in spectrum, wave, and vector representation

(a). Unmodulated conditions
(b). Modulation producing side-band power of four times unmodulated carrier power in amplitude-modulation system

carrier-frequency wave at the receiving end of the channel, produces a variation in the amplitude of the resultant wave twice as great as the variation in the amplitude of the signal transmitted by the same apparatus in amplitude modulation. This is an additional gain of six decibels, which added to the three decibels gained by reducing the channel width gives a total gain for the single-side-band system of nine decibels over the amplitude-modulation system, with the same apparatus and the same peak transmitted power. In other words, the single-side-band system provides the equivalent of an amplitude-modulation system of eight times the carrier power and occupies only half the amplitude-modulation channel width.

Equations 4 and 6 provide a means of comparing directly the performance of the frequency-modulation and single-side-band systems in the presence of random noise. Dividing equation 4 by equation 6 we get

$$\frac{E_{F-M}}{E_{SSB}} = \frac{f_{max}}{\Delta F}\sqrt{\frac{2}{3}} \quad (7)$$

The two systems cannot be compared on the basis of the same required channel width, because at least the first pair of side-band components must be transmitted in the frequency-modulation system. Even though the peak-to-peak frequency swing $2\Delta F$ of the frequency-modulation signal is limited to the band width of the single-side-band signal, the first pair of side-band components required to produce the swing occur at carrier frequency plus and minus audio frequency, as in the amplitude-modulation system. For a maximum audio frequency of three kilocycles, a comparison can be made between the single-side-band system with a three-kilocycle band width and the frequency-modulation system with the minimum band width of six kilocycles. The requirement that the frequency-modulation band width be at least $1.5 \times 2\Delta F$ gives a maximum value of two kilocycles for ΔF, for which equation 7 shows a gain of 1.8 decibels for the single-side-band system, with a peak power which is reached only intermittently during conversation, equal to the continuously transmitted power of the frequency-modulated signal. If advantage is taken of the power capability of an efficiency-modulated amplitude-modulation transmitter to amplify the single-side-band signal, as discussed in the previous paragraph, the additional gain of six decibels brings the total gain to 7.8 decibels. In all cases the frequency-modulated signal requires at least twice the band width of the single-side-band signal.

Other Advantages of the Single-Side-Band System

Reduction in channel width and gains in signal-to-noise ratio in the presence of random noise are by no means the only advantages offered by the single-side-band system in power-line carrier work. A severe type of interference occasionally

encountered on power systems is the type known as corona modulation,[4] a phenomenon in which the amplitude and phase of an amplitude-modulated or a frequency-modulated carrier are modulated in a complex manner by the presence of space charge due to corona. This space charge varies the effective shunt conductance of the line, periodically changing its attenuation and phase-shift constants. It has been found that increasing the power of the carrier fails to alleviate this condition, because the relative amount of modulation apparently stays the same, maintaining the same signal-to-noise ratio. The single-side-band system offers an ideal solution of this problem, because the carrier is supplied at the receiving end of the channel and therefore is not subjected to this type of modulation.

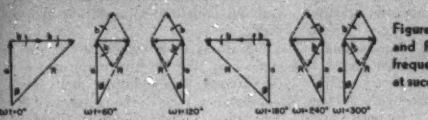

Figure 7. Addition of carrier and first side-band pair in a frequency-modulation system at successive intervals during an audio cycle

One of the most important features of the single-side-band system is that the absence of the carrier signal permits many applications that are impossible with the amplitude-modulation and frequency-modulation systems, in which a continuous carrier is transmitted. Elimination of the carrier permits a single receiver to receive signals from several different transmitting points simultaneously. For example, different telemetering tones can be used to modulate single-side-band transmitters at each of several locations, all on the same nominal carrier frequency. These transmitters can all be received simultaneously on a single receiver, because there is no beat-note interference and elimination of weak signals by strong ones as is the case with the amplitude-modulation or frequency-modulation systems.

Elimination of the carrier wave also permits repetition of carrier frequencies for separate-tone telemetering and load-control channels, even though these channels may be physically near each other on the power system. All that is required is that the strength of the desired signal be comparable to that of the undesired signal at the receiving point. It is not even necessary that the desired signal be as strong as the undesired one. Separate-tone frequencies must be used for each function, of course, but the nominal carrier frequencies can be the same.

An outstanding feature of the single-side-band system results from its similarity to the amplitude-modulation system. Basic amplitude-modulation transmitter and receiver units, with the unit type of rack-and-panel construction,[5] can be designed so that they can be converted in the field to single-side-band operation by the addition of single-side-band panel units. This makes it possible for utilities which do not at present have spectrum-crowding or interference problems to install suitably designed basic amplitude-modulation equipment for their present purposes, with the assurance that should such problems arise later they can be coped with by conversion of the amplitude-modulation equipment to the single-side-band system.

Conclusions

It is possible with the frequency-modulation system to obtain large gains over the amplitude-modulation system in signal-to-noise ratio. However, these gains are proportional to the deviation ratio employed and can be obtained only at the expense of channel width in the carrier-frequency spectrum. In the presence of random noise, a frequency-modulation system of unity deviation ratio provides a gain of 4.8 decibels in signal-to-noise ratio over an amplitude-modulation system of the same carrier power but requires a channel width at least 50 per cent greater for reasonably distortion-free audio reproduction.

The single-side-band system is a more sound approach to the two main problems that confront utility engineers in applying power-line carrier equipment. In this sytem gains in signal-to-noise ratio are obtained by using the entire transmitted power for intelligence-bearing signals and concentrating this power in a narrow frequency band. With half the transmitted band width, the single-side-band system provides a gain in signal-to-noise ratio of nine decibels over the amplitude-modulation system, with a power equal to the peak power of the amplitude-modulated signal. The absence of a continuous carrier in the single-side-band system makes possible the repetition of carrier frequencies for some applications and further increases the gains in channel space it provides. The similarity of the single-side-band system to the amplitude-modulation system makes it possible to convert to the single-side-band system present and future installations of amplitude-modulation equipment of suitable design.

Appendix. Distortion of a Frequency-Modulated Signal Caused by Suppression of All Except the First Pair of Side-Band Components

In a frequency-modulation system, the resultant of the first pair of side-band components is always in quadrature with the carrier component. The magnitude of this resultant varies at the modulating frequency between the limits of plus and minus twice the amplitude of the individual side-band components. These relations are shown in Figure 7 in vector form for successive points on an audio cycle. The vector obtained by adding the carrier vector to the resultant of the side-band vectors has with respect to the carrier vector a phase position ϕ which can be expressed for any instant of time as

$$\phi = \text{arc tan } \frac{2b \cos \omega t}{a} \tag{8}$$

where b is the amplitude of each side-band component, ω is 2π times the modulating frequency, and a is the amplitude of the carrier component. If the amplitude variations of the resultant are removed by limiters, the discriminator of a frequency-modulation receiver responds only to the rate of change of phase of the resultant signal, that is, to

$$\frac{d\phi}{dt} = \frac{-(2b\omega/a) \sin \omega t}{1+(4b^2/a^2) \cos^2 \omega t} \text{ radians per second} \tag{9}$$

Dividing equation 9 by 2π, we get the equivalent instantaneous frequency deviation,

$$F_i = \frac{-(2bf/a) \sin \omega t}{1+(4b^2/a^2) \cos^2 \omega t} \text{ cycles} \tag{10}$$

in which f is the modulating frequency in cycles. The curves of Figure 4 were obtained by substituting the proper values for a and b from a table of Bessel functions, assuming a frequency-modulation system with unity deviation ratio and three kilocycles maximum audio modulating frequency.

References

1. Frequency Modulation for Power-Line Carrier Current, E. W. Kenefake. AIEE Transactions, volume 62, 1943, October section, pages 616–19.

2. Frequency Modulation, W. L. Everitt. AIEE Transactions, volume 59, 1940, November section, pages 613–25.

3. Frequency Modulation (book), Angus Hund. McGraw-Hill Book Company, Inc., New York, N. Y., 1942.

4. Problems in Power-Line Carrier Telephony, W. V. Wolfe, J. D. Sarros. AIEE Transactions, volume 48, 1929, pages 107–13. Also closure by J. D. Sarros, pages 115–16.

5. A Versatile Power-Line Carrier System, H. W. Lensner, J. B. Singel. AIEE Transactions, volume 63, 1944, March section, pages 129–32.

The Amplidyne Generator Applied to Speed-Controlled Electric Gun Turrets for Aircraft

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THE PURPOSE of this paper is to explain the action of a particular type of Amplidyne generator in terms of its relationship to the turret performance and to attempt to separate its characteristics from those of the turret.

Development of this Amplidyne generator and the outbreak of the war were concurrent, and, due to incomplete knowledge of the requirements of this type of generator, it was expedient to define the characteristics of the turret control system as a whole. This caused difficulties in applying the Amplidyne to other systems. The characteristics of the Amplidyne can be defined independently of the system. Some effects of the variations in the Amplidyne characteristics and changes in circuit constants on the over-all performance of the turret will be shown.

Function of the Turret Power Drive

Most turrets using these Amplidynes are powered in both elevation and azimuth, by means of two separate control systems each consisting of a turret motor, an Amplidyne, and a control circuit.

The Amplidyne is part of a motor-generator set driven from the electric system of the airplane and makes available readily controlled power to operate the turret motor. By varying the adjustment of certain potentiometers connected in the control-field circuit of the Amplidyne, its output, and hence the performance of the turret, may be controlled by the operator.

The control circuit is used to combine properly the characteristics of the Amplidyne with those of the turret motor to produce the desired over-all performance of the system.

An important characteristic of the power drive is that of constant speed for a given potentiometer setting, independent of the gun position with respect to the wind. Another very important requirement of the power-drive system is that it be capable of driving the turret smoothly at very low speed. In direct contrast to this characteristic is the necessity for the turret power system to be capable of turning the turret rapidly from one target to another.

Description of the Amplidyne

The Amplidyne under consideration constitutes the generator end of a two-bearing motor-generator set. The 27-volt d-c driving motor is on the same shaft as the Amplidyne generator and drives it at about 8,300 rpm. The driving motor is an eight-pole compound-wound motor with one series turn to obtain quick starting and decrease the inrush current. This enables the unit to start and attain 85 per cent of its rated no-load speed in less than one second. The generator is rated at 60-volts 8.8-amperes output for ten minutes on and 20 minutes off. Figure 1 shows a complete Amplidyne set; Figure 2 is a sectionalized view showing the internal construction.

The generator has a two-pole stator with a control-field winding, F (see Figure 3), and compensating-field winding, H, acting in the load axis. Two rheostats are shunted across the compensating field for adjustment. An additional control field, G, acting in the same axis is provided for antihunt purposes. There is also a winding in the quadrature axis. The generator has four brushes mounted on an adjustable mechanism and spaced 90 degrees apart. Two diametrically opposite brushes, C, are connected in series with the compensating winding and the output terminals of an AN connector to constitute the load axis. The other two brushes, D, are short-circuited to complete the quadrature circuit. The operation is, briefly, as follows. Full-field excitation of the order of 0.1 watt in the control-field winding causes a small flux in the load axis which generates an electromotive force of about ten volts acting in the quadrature axis. This voltage then causes current to flow through the quadrature brushes, which in turn sets up a quadrature magnetic field. This field then causes an electromotive force of approximately 90 volts to be generated across the load brushes. As soon as a load current is allowed to flow, the compensating winding more than compen-

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Figure 1. A typical aircraft Amplidyne for turret control

Figure 2. Cut-away views showing the internal construction of the Amplidyne

The upper illustration is the generator end and the lower is the motor end

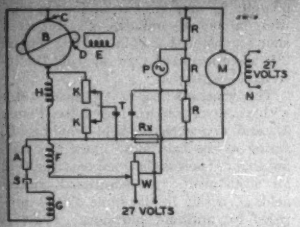

Figure 3. A typical elementary circuit diagram with fixed feedback

A —Antihunt resistor
B —The Amplidyne rotor
C —Amplidyne load brushes
D —Amplidyne quadrature brushes
E —Short-circuited quadrature winding
F —Control field
G —Antihunt field
H —Compensating winding
K —Compensating adjusting rheostats
M —Turret-motor armature
N —Turret-motor shunt field
P —Vibrator inverter transformer
R —Fixed-feedback resistors
S —Capacitor for antihunt
T —Normally open contactors operated simultaneously
W —Control potentiometer

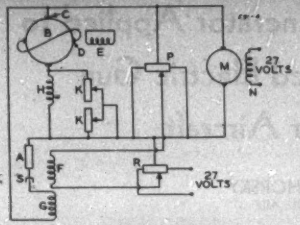

Figure 4. A typical elementary circuit diagram with variable feedback

A —Antihunt resistor
B —The Amplidyne rotor
C —Amplidyne load brushes
D —Amplidyne quadrature brushes
E —Short-circuited quadrature winding
F —Control field
G —Antihunt field
H —Compensating winding
K —Compensation-adjusting rheostats
M —Turret-motor armature
N —Turret-motor shunt field
P —Variable-feedback potentiometer
R —Control potentiometer coupled to variable-feedback potentiometer
S —Antihunt capacitor

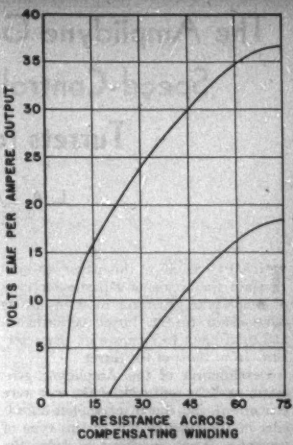

Figure 5. Curves showing generated electromotive force per ampere of load current versus resistance across compensating winding

The two curves differ by three per cent of compensating-winding turns

sates for its armature-reaction effect. The amount of overcompensation, measured in volts per ampere output, is readily adjustable by means of the two rheostats, *K*, connected in series across the compensating winding, *H*, as shown in Figure 3. The curves in Figure 5 show the effectiveness of the rheostats. The difference between the two curves is the effect obtained by changing the compensating winding on one pole by approximately 3.0 per cent.

Detailed Operation of the Amplidyne

The Amplidyne-generator control field is excited by means of a control potentiometer. A resistor used as a voltage divider, *R*, is connected across the Amplidyne output and provides a negative feed-back voltage in the control-field circuit. Figure 3 shows a typical circuit arrangement. The amount of feedback is adjustable by a contactor, *T* as in Figure 3, or in some cases by a potentiometer as in Figure 4. When a contactor is used, two ranges of turret operation are obtained, a low or normal range for tracking and a high-speed range for sluing. The circuit in Figure 4 gives a gradual transition from the low-speed range to the high-speed range.

The amplification thus obtained is extremely great for d-c generators with very low time constants, and therefore special consideration has been given to maintaining a stable system. The following three methods are used to help prevent instability in the system: First, there is a short-circuited quadrature winding (*E* in Figure 3) to decrease irregularities in the output voltage caused by commutation irregularities of the quadrature brushes. Without the short-circuited winding to dissipate the energy thus generated, the irregularities may be amplified by the quadrature flux and be apparent as unsteady output voltage. Second, there is a capacitor and resistor in series with an antihunt field intended primarily to prevent the turret motor from overshooting the desired speed. When the excitation of the Amplidyne is changed, the Amplidyne will attempt to establish very quickly the new output desired. Since it has a turret-motor load which furnishes a back electromotive force, the output current of the Amplidyne often is reversed completely when the control handles are moved so as to decrease the speed of the turret. The antihunt circuit admits a current through the antihunt windings in proportion to the rate of change of voltage across the turret-motor armature. Therefore, when the turret motor is changing speed rapidly, the antihunt field is furnishing the Amplidyne an excitation to oppose this change. Third, there is the feed-back voltage connected in series with the control potentiometers. The action of the voltage from this feedback approaches that of a voltage regulator. If the control field were connected completely across the Amplidyne output voltage, instead of just over a portion of the output voltage, the system would approach a voltage-regulator system. Therefore, the output voltage would be nearly independent of the output current, if the control fields were connected completely across the Amplidyne output. The magnitude of the effect of the feedback is shown in Figure 6. Curve *A* is the characteristic obtained with no feedback, whereas curve *B* is with 6.0 per cent feedback. Per cent feedback is the per cent of the resistance across the Amplidyne output that is in series with the control field.

A rising characteristic with increase in load is needed to obtain constant turret-motor speed. This is obtained by

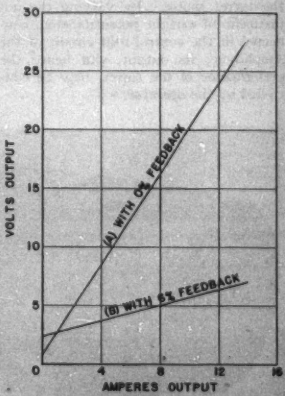

Figure 6. Volt-ampere characteristic curve with and without feedback

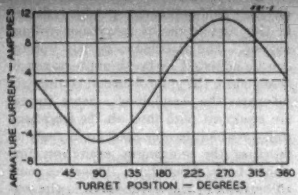

Figure 7. Armature current versus turret position measured from forward position

the compensating winding which, as mentioned above, more than compensates for the armature reaction and the *IR* drop in the Amplidyne.

Figure 7 shows an idealized curve of turret-motor armature current versus the angular position of the turret. It is apparent from inspection of the curve that it is a sine curve plus a constant. The constant is the turret friction measured in armature amperes of the turret motor. The magnitude of the sine curve is the torque exerted on the gun turret due to the wind load.

The typical turret motor is a separately excited shunt-wound machine the speed-torque characteristic of which is shown in Figure 8. Figure 9 shows the characteristic of speed versus input ampere to an enlarged scale starting at 200 rpm no load. For easy operation of the turret it is desirable that the speed regulation of the turret motor be less than 30 per cent from no load to full load for all speeds down to as low as 200 rpm. This demonstrates the need for the rising characteristic of the Amplidyne shown in Figure 6 previously discussed. By combining in the right proportions the rising characteristic of the Amplidyne with the falling characteristic of the turret motor, the results shown in Figure 10 are obtained. These results are obtained in a circuit with a switch to change from normal tracking-speed range to sluing-speed operation by changing the feed-back ratio. Figure 11 shows the results obtained in a circuit using the variable feedback as shown in Figure 4. In the system with variable feedback, if the compensation be adjusted correctly with the controls set to run the motor at 600 rpm, this adjustment will be incorrect when running the motor at 200 rpm, and the motor will stall before full load is reached. If adjusted for flat regulation similar to Figure 10 at 200 rpm, the compensation will be too great at 600 rpm and above, and the turret motor will speed up under load. This is true of a particular combination of circuit, turret motor, and Amplidyne. If a fixed resistance be added in series with the center tap on the feed-back potentiometer (*P* in Figure 4), very nearly flat compensation can be obtained over the entire speed range.

The system is very critical with respect to resistance added in series with the turret-motor armature and Amplidyne. Figure 12 shows the result of test taken where per cent of regulation was plotted versus series resistance added in the control circuit as R_s in Figure 3 between the Amplidyne and the turret motor. Very nearly the same effect is obtained by changing the armature resistance of the turret motor. The armature resistance of the turret motors which have been used by various manufacturers of turrets has varied over the range from 0.29 ohm to 0.90 ohm. These Amplidynes were not successful in being adjustable over this wide range and still able to meet other performance requirements of the turret. This range in resistance of turret motors has been decreased to approximately 0.29 ohm to 0.60 ohm. All tests and users reports indicate that the Amplidynes are capable of being adjusted with the rheostats on the Amplidynes over a range wide enough to compensate for this much resistance change in the turret motors.

In Figure 10, it is noticed that the speed versus ampere input to the turret motor, when used in the turret control circuit, is not a line but a closed loop. The curve was taken as follows: The turret motor was set at full-load current input, then this load was gradually decreased to the no-load current value. The speed was noted, and then the load was increased gradually while recording values of speed until full load again was obtained. Then the load was decreased slowly, recording speed values until the no-load speed again was obtained. The hysteresis lag in the stator iron of the Amplidyne causes the two curves not to coincide. The drop in speed as the load increases is caused by the lag between the magnetizing effect of the load current in the compensating winding, and the flux in the iron. As the magnetizing current in the compensating winding becomes greater, the percentage flux lag becomes much less, and therefore the curve begins to flatten out. In decreasing the load, the flux does not decrease immediately with the decrease in magnetizing current in the compensating winding, thus giving the rising characteristic on decreasing load. If a true one-half hysteresis curve were taken by this method, an open curve with two different speeds at the no-load end of the curve would result. Since, however, the curve was started at full load and carried through to no load, the turret motor had to return to the same no-load speed it started from the first time. Therefore the closed curve shown is obtained.

This objectionable change in speed can be eliminated by preventing the occurrence of residual voltage in the Amplidyne generator. A source of 60-cycle alternating voltage connected in series with the control field will decrease materially this speed change, as is apparent in Figure 13. This has been accomplished in some instances by a vibrator-type inverter transformer and is illustrated by *P* in Figure 3.

As an interesting sideline, it is apparent

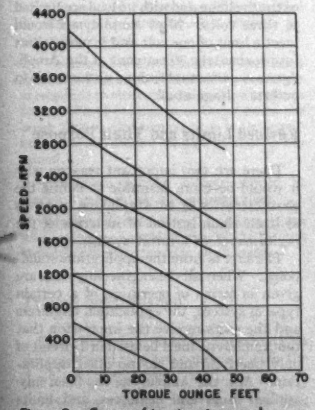

Figure 8. Curves of turret-motor speed versus output torque with constant voltages at 10-volt intervals from 10 to 60 volts

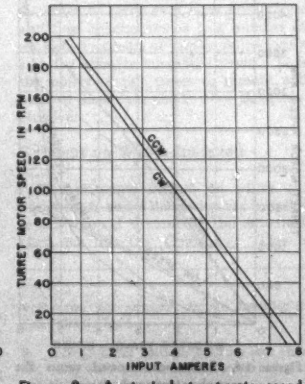

Figure 9. A typical turret-motor-speed-versus-input-ampere curve at approximately five per cent of rated no-load speed

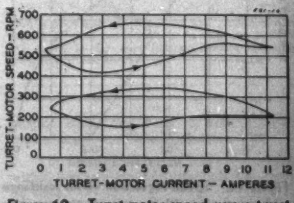

Figure 10. Turret-motor speed versus turret-motor armature current in a typical turret not using a vibrator inverter

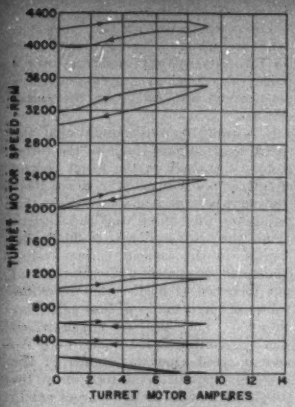

Figure 11. Turret-motor speed versus turret-motor armature current for the circuit shown in Figure 4

that tests taken with the inverter used with the Amplidyne can show the compensation characteristics more nearly than tests with the inverter left out. Some of these Amplidynes have an undeserved reputation for being inconsistent in test. If the unit be warmed up thoroughly and the inverter used, very consistent test results can be obtained. Without the alternating current it is very difficult to repeat compensation readings, as is evident from inspection of the characteristics without it.

The curves of Figure 14 are presented to show the wide range of performance that may be obtained with different control-circuit arrangements. The two circuits given in Figures 3 and 4 were used to obtain these curves. The solid lines are

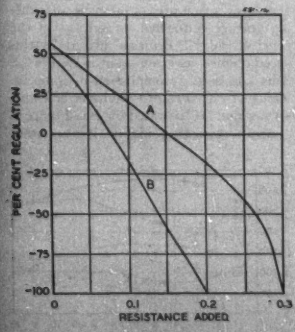

Figure 12. Speed regulation versus resistance added in series with the turret-motor armature

A—15 ohms feed-back resistance
B—75 ohms feed-back resistance

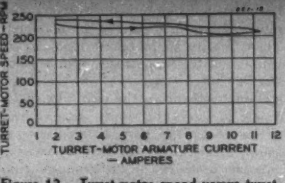

Figure 13. Turret-motor speed versus turret-motor armature current for the same turret circuit as in Figure 10, except that a vibrator inverter has been added and the Amplidyne compensation readjusted

the no-load speed versus potentiometer position, and the dashed lines are the full-load speed versus potentiometer position. These curves illustrate that the speed regulation of the system is practically zero throughout the entire rheostat travel in the low-speed range and is practically flat up to about 40 per cent of maximum speed in the high-speed range. With the variable feedback there are two places at which the compensation is correct. The first place is at the low speed at which the compensation is adjusted. The second place is at a higher speed where the Amplidyne has begun to saturate. The overcompensating effect is decreased as a result of this saturation until the drooping characteristic of the turret motor equals the overcompensation of the Amplidyne.

Some turret specifications require that the turret have a maximum speed less than a certain value to prevent failure of some mechanical part, whereas other turret specifications require that the maximum turret speed be over a certain value in order to meet speed require-

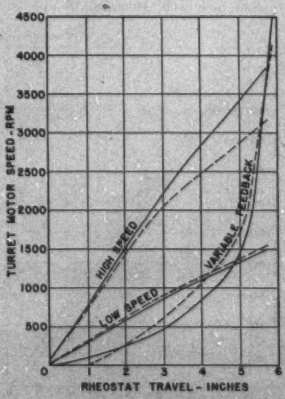

Figure 14. Turret-motor speed versus the control-potentiometer travel

——No-load speed
— — —Full-load speed

ments. This maximum speed is reflected in the Amplidyne as maximum voltage output. The maximum output voltage can be adjusted by brush shift, except in cases where the control circuit completely saturates the Amplidyne. Some turrets are equipped with taps on the feed-back resistor which can be used to increase or decrease the maximum excitation furnished to the Amplidyne. This gives some adjustment of the turret speed in the systems where control does not completely saturate the Amplidyne.

Present Specifications for the Amplidyne

The present specifications for Amplidynes are in terms of the performance of a complete turret control system. Most of the test limits that are used to adjust the Amplidyne are based on the speed of the turret motor at various loads and control potentiometer settings. A particular set of limits follows for a 530-watt Amplidyne and 3,000-rpm motor for use in the circuit shown in Figure 3.

Circuit Condition of Contactor, T	Turret Motor Rpm	
	No Load	Full Load
Closed	200	200 ± 20%
Closed	3,400	3,400 ± 20%
Open	200	200 ± 20%
Open	1,200	1,200 ± 20%

To prevent instability in the system due to the brushes of the Amplidyne being shifted too far against rotation, a limit of six volts is imposed as the maximum residual output voltage allowed with zero control-field excitation.

The irregularities of the Amplidyne voltage output at one quarter of its rated output voltage and with no load are limited to three volts. Most Amplidynes would meet a limit of one volt and in many cases (approximately 30 per cent of the Amplidynes manufactured) show no variation in output voltage at all.

Revised Limits and Their Purpose

There are two important reasons why it would be more desirable to define the characteristics of an Amplidyne in terms of itself alone instead of in terms of the performance of a turret system.

The first is from the application standpoint. When all the engineering data are given in terms of operation of a certain type of system, the application engineers and the users receive the impression that the Amplidyne must be used in a circuit of only one type and has no other application. Also the Amplidyne has been misapplied in several instances, and limits have been placed on the operation of a turret which are correlated in no way with the actual performance of the Amplidyne

and its range of adjustment. If the characteristics of the Amplidyne be given as a unit, the allowable variations on these values listed, the application engineer can apply the Amplidyne to any circuit he wishes and know what to expect the system to do.

The second is for complaint and trouble shooting. When a turret manufacturer or an ultimate user experiences some difficulty meeting his specifications, it is difficult to determine whether or not the Amplidyne is at fault. If the characteristics of the Amplidyne were defined in terms of the Amplidyne alone, the machine could be set up on a test bench and tested. There are many possible defects in a turret which might affect its over-all characteristics and which could be attributed incorrectly to the Amplidyne, because the performance of the Amplidyne alone was not known.

Each value in a specification should have a definite purpose so far as the machine being described is concerned without reference to the system operation as a whole. The specification should describe how the Amplidyne should be adjusted and should limit the adjustments directly in terms of the Amplidyne characteristics. The following gives in brief form the type of specification needed to adjust an Amplidyne properly:

1. No-load saturation-curve slope should be specified to limit the position of the brushes. Shifting the brushes against rotation of the Amplidyne increases the voltage output for a given excitation.

2. The compensation should be adjusted to a curve similar to the zero feed-back curve of Figure 6 by adjusting the rheostats and the taps on the compensating winding to obtain zero-per-cent voltage regulation with a given increase in field current opposing the output current.

3. The residual voltage should be specified for those applications where a vibrator inverter is not used.

4. Commutator-film-breakdown excitation should be limited to minimize the dead spot in response to the control signal. It takes a finite value of excitation to break down the brush film on the commutator in the quadrature circuit before output voltage is obtained.

5. Maximum output voltage should be specified to maintain all machines alike.

6. Maximum output watts with a given load resistance should be checked to be sure the unit will withstand the peak loads.

Typical Specification

The following sample specifications are numbered in correspondence with the foregoing paragraphs.

1. One-half voltage (30 volts) no load must be obtained with an excitation of 0.020 ampere to 0.040 ampere in the control field.

2. The voltage regulation shall be 2.0 volts rise per ampere output starting at 4.0 volts no load.

3. The residual voltage shall be less than six volts with zero field after saturation of the field.

4. Increasing excitation from 0 to 0.006 ampere shall produce a change in no-load output volts from 5 to 12 volts starting from a negative residual voltage.

5. The no-load output voltage of the unit with 0.250-ampere excitation shall be 85 to 95 volts.

6. The unit shall be capable of operating for five seconds with a load of 925 watts at 15.4 amperes output.

Nine Years' Experience With Ultrahigh-Speed Reclosing of High-Voltage Transmission Lines

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Synopsis: Data covering nine years' operating experience with 91 ultrahigh-speed-reclosing breaker installations mainly on a large interconnected and integrated high-voltage system are presented and analyzed: out of 635 cases of flashover cited, 570 reclosures were successful and 65 cases of reclosure were unsuccessful, a record of 89.8-per-cent successful reclosure. Double-circuit lines show a record of unsuccessful reclosure double the average but 80 per cent of the apparently unsuccessful reclosures resulted in successful reclosure of one circuit. The conclusions drawn are that ultrarapid reclosure has proved itself a tool of major importance for use in improving high-voltage line reliability; that its use can, and should be, extended to lower-voltage lines, and that further improvements are in sight as a result of recent improvements in circuit-breaker opening and reclosure time.

SINCE the last publication[1] of operating experience with ultrahigh-speed reclosing of high-voltage transmission lines, four more years of operating experience have been gathered on lines of the American Gas and Electric Company systems. This experience is of so much more extensive a nature than that available previously that it now makes possible not only more thorough checking of ideas and conclusions previously entertained but not entirely proved, but, in fact, it appears that sufficient data now have been made available to serve as a basis for definite and final conclusions as to a number of important aspects of ultrarapid reclosure and the benefits inherent therein. It is the object of this paper to present and analyze these data and to draw these conclusions.

Systems on Which Installed

The principal system on which the equipments under discussion are installed is the central system of the American Gas and Electric Company. This is shown diagrammatically in Figure 1 in its most up-to-date form. This integrated system operates in seven states and consists of 45 circuit miles of 154-kv, 2,818 circuit miles of 132-kv, 64 circuit miles of 110-kv, 304 circuit miles of 88-kv, and 695 circuit miles of 66-kv high-voltage circuits. Most of the 132-kv circuits are of double-circuit steel-tower construction. It is to be noted that neither the 88-kv nor the 66-kv lines are indicated in Figure 1. However, there are only three terminals installed on the 88-kv circuits and only six terminals on the 66-kv circuits; as against that there are installed 72 terminals on the 154- and 132-kv circuits.

The load which the central system serves has had a maximum one-hour integrated peak of over 1,450,000 kw. As pointed out previously, the system is a predominantly steam-electric system with a small portion of hydroelectric generating capacity. Extensive and important foreign interconnections exist on several portions of the system through which diversity and other capacity exchanges are carried out with adjacent systems. Because of the fact that practically all the energy served on the system travels over considerable transmission distance before reaching the load and because of sudden changes in power flow, it has been found particularly important to maintain maximum continuity in the operation of transmission networks. Obviously this in turn results not only in the rendering of the utmost in high continuity of service, but also makes possible the operation of the system in a most co-ordinated manner

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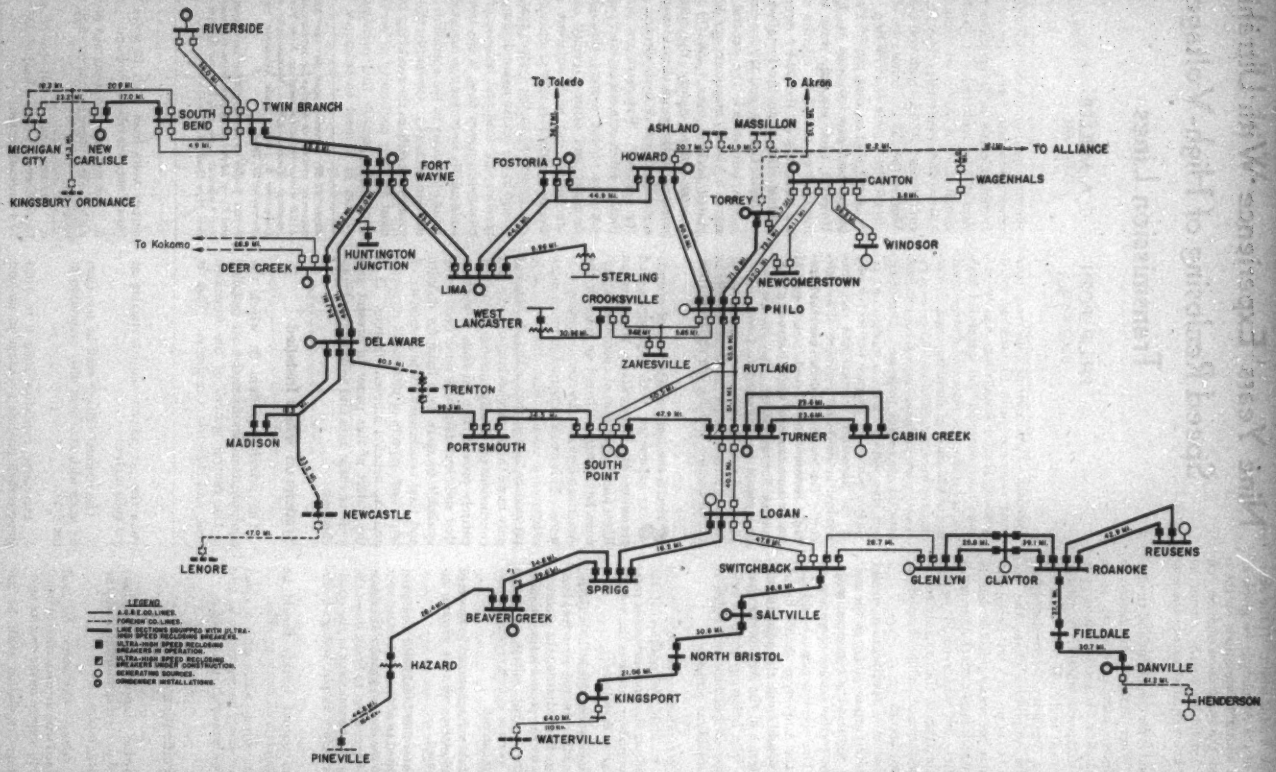

Figure 1. Ultrahigh-speed-reclosing oil-circuit-breaker installations on the 132-kv transmission system of the central system of the American Gas and Electric Company

Table I. Summary of Actual Operations of Ultrahigh-Speed-Reclosing Oil Circuit Breakers, May 1936 to November 1944

Line	Line Voltage (Kv)	Length of Line (Circuit-Miles)	Number of Terminals	Date of Installation	Ultrahigh-Speed Oil-Circuit-Breaker Operations: Number of Operations 1936	1937	1938	1939	1940	1941	1942	1943	1944	Total	Number of Successful Reclosures 1936	1937	1938	1939	1940	1941	1942	1943	1944	Total	Number of Unsuccessful Reclosures 1936	1937	1938	1939	1940	1941	1942	1943	1944	Total
Hazard–Pineville	154	45.0	2	4/11/42							1	2	2	5								1	2	4								1		1
Fort Wayne–Deer Creek	132	59.2	2	5/17/36	4	5	3	1	3	4	2	4	1	27	3	4	3	1	3	3	2	3		22	1	1			1		1		1	5
South Bend–New Carlisle	132	17.0	2	1/29/38		1	1			2				4		1	1			2			1	5								1	1
No. 1 Twin Branch–Fort Wayne	132	65.4	2	8/31/38			1	2	2		5	8	5	23			1	2	2		5	8	4	22								1	1
No. 2 Twin Branch–Fort Wayne	132	65.4	2	7/25/38		2	3	1			2	3	1	12		2	3	1			1	3	1	11								1		1
No. 1 and No. 2 Twin Branch–Fort Wayne	132		4	8/31/38			2				4	3	2	11			1				4	2	2	9				1			1		2
North Bristol–Kingsport	132	21.1	3	3/20/40					6	8	1	4	5	24						4	8	1	4	5	22					2				2
Saltville–North Bristol	132	30.8	2	3/22/40					6	9	1	11	4	31						6	9	1	8	2	26						3	2		5
Roanoke–Fieldale	132	37.4	2	4/28/40					12	6	10	14	7	49						12	6	9	13	7	47						1	1		2
No. 1 Roanoke–Reusens	132	42.9	2	5/ 1/40						2	7	10	6	25							2	7	98	6	24						1			1
No. 2 Roanoke–Reusens	132	42.9	2	5/ 1/40						3	1		2	7							3	1		2	7									
No. 1 and No. 2 Roanoke–Reusens	132		4	5/ 1/40					6	7	14	14	7	48						4	4	12	9½	5	34½					2	3	2	4½	2	13½
No. 1 Philo–Howard	132	80.6	2	5/ 2/40					3	4	3	1	4	15						3	4	3	1	4	15									
No. 2 Philo–Howard	132	80.6	2	5/20/40					3	3		2	4	82						3	3		2	4	12									
No. 1 and No. 2 Philo–Howard	132		4	5/20/40								3	4	7								3	4	7									
Fort Wayne–Delaware	132	77.9	3	5/26/40					1	5	5	8	5	24						1	8	5	6	4	20					1	2		1	4
Turner–South Point	132	47.9	2	8/ 1/40					8	10	26	12		56						10	26	8	128		56									
Fostoria–Lima	132	44.6	2	10/ 3/40							2		4	6							2		2	4								2		2
Delaware–Newcastle	132	41.7	3	1/ 9/41						1	5	3	3	12							1	4	2	3	10						1	1		2
No. 1 Cabin Creek–Turner	132	23.6	2	5/ 1/41						2	1		5	8							2	1		5	8									
No. 2 Cabin Creek–Turner	132	23.6	2	5/ 1/41							2	2	2	6								2	2	2	6									
No. 1 and No. 2 Cabin Creek–Turner	132		4	5/ 1/41						3	4	3	5	15							3	3	3	5	14						1			1
No. 3 Cabin Creek–Turner	132	23.6	2	5/12/43								2		2								2		2									
Delaware–Trenton	132	80.3	2	8/26/41							1	4	1	6								1	3	1	5							1		1
Philo–Torrey	132	70.7	2	1/ 8/42							2	2	5	9								2	2	5	9									
Delaware–Madison	132	18.5	2	1/23/42							1	4		5								1	4		5									
Beaver Creek–Hazard	132	28.4	2	2/ 1/42							5	11	2	18								5	11	2	18									
No. 1 Glen Lyn–Claytor	132	25.8	2	3/22/42							5	3	8	16								5	3	8	16									
No. 2 Glen Lyn–Claytor	132	25.8	2	3/22/42							2		2	4								2		2	4									
No. 1 and No. 2 Glen Lyn–Claytor	132		4	3/22/42							1		1	2								1		½	1½								½	½
No. 1 Claytor–Roanoke	132	39.1	2	5/ 1/42							5	9	2	16								5	9	1	15								1	1
No. 2 Claytor–Roanoke	132	39.1	2	5/ 1/42							1	5	2	11									6	2	8							1	2	3
No. 1 and No. 2 Claytor–Roanoke	132		4	5/ 1/42								3		3									2½		2½							½		½
Deer Creek–Delaware	132	24.1	2	6/25/42							1	2	1	4								1	2	1	4									
Lima–Sterling	132	5.95	1	1/ 6/43								1		1									1		1									
No. 1 Logan–Sprigg	132	18.1	2	3/ 5/43									1	1										1	1									
No. 2 Logan–Sprigg	132	18.1	2	3/ 5/43								1	3	4									1	2	3								1	1
No. 1 and No. 2 Logan–Sprigg	132		4	3/ 5/43								2	9	11									2	5½	7½								3½	3½
Sprigg–Beaver Creek	132	39.6	2	3/17/43								13	12	25									13	7	20								5	5
Fieldale–Danville	132	30.8	2	6/27/43								3	8	11									3	8	11									
Crooksville–West Lancaster	132	30.96	2	8/ 8/43										0											0									
Switchback–Saltville	132	38.8	3	6/22/44										0											0									
Baileysville–Coalwood	88	15.9	3	12/ 5/43									4	4										2	2								2	2
No. 1 Deepwater–Atlantic City	66	63.1	2	6/27/40						2		1	1	8	12						2		1	1	7	11								1	1
No. 2 Deepwater–Atlantic City	66	63.1	2	6/27/40					3	6		1		4	14						3	6		1	3	13								1	1
No. 1 and No. 2 Deepwater–Atlantic City	66		4	6/27/40					1	2		1	2	4	10						1	2	1	2	4	10									
No. 1 Stanton–Suburban	66	10.9	3	6/29/40								2		2	2									2	2									
No. 2 Stanton–Suburban	66	10.9	3	6/29/40								1		1	1									1	1									
No. 1 and No. 2 Stanton–Suburban	66		6	6/29/40										0											0									
No. 2 Crooksville–Newark	66	32.7	2	8/ 8/43								3	5	8								3	5		8									
Newark–Lancaster	66	30.74	2	8/ 8/43								2	7	9								2	5		7								2	2
West Lancaster–Anchor Hocking	66	1.34	2	8/ 8/43										0											0									
Total		1,634.1	91		4	5	6	8	50	77	107	196	172	635	3	4	6	7	46	72	100	177	155	570	1	1	1	4	5	7	19	27	65	

and the utilization at all times of the most efficient combination of generating sources regardless of their location.

In addition to equipments on the central system, four terminals have been in operation on 66-kv lines of the Atlantic City Electric Company and six terminals on 66-kv lines of The Scranton Electric Company, bringing the total of terminals in service of the latest date to 91.

Operating Experience

A summary of the total operating experience since the first installation is given in Table I. Referring to that table, it will be seen that a total of 91 terminals involving 43 line sections have been covered and that these 43 line sections cover approximately 1,634 circuit miles of line, 1,360 miles of which operate at 132,000 volts. In the period May 1936 to November 1944, covering substantially nine lightning years, 635 cases of flashover resulting in line opening occurred. Of these, 531 cases were single-line trouble and 104 cases were two-line trouble. Out of the same number of 635 cases of flashover, 570 reclosures were successful and 65 cases of reclosures were unsuccessful. This is a record of 10.2-per-cent unsuccessful reclosures. In this connection it needs to be pointed out that in eight of these cases a permanent fault existed on the line and that under such conditions obviously successful reclosure was a physical impossibility, since nothing but a permanent outage could clear the trouble. These permanent faults were caused by either lines being on the ground, physical damage to steel tower, failure of a lightning arrester, or a string of insulators pulling loose because of ice loading. If one chooses to disregard these eight cases, the total unsuccessful reclosures were 57, representing 9.0 per cent. It is interesting to note that for the 104 cases of two-line trouble, 21 unsuccessful reclosures were experienced, giving an unsuccessful percentage of 20.2 per cent for simultaneous trouble on two lines. The method of scoring employed for recording unsuccessful reclosures for two-line trouble was this: in cases where only one line of the two reclosed successfully, the operation was credited with one-half unsuccessful reclosure, and in cases where neither line reclosed successfully, the operation was credited with a full unsuccessful reclosure. Since in 80 per cent of the cases of reclosures on two-line trouble which were not fully successful one of the two lines reclosed successfully, it is evident that the scoring method adopted reflects, if anything, a pessimistic version of the effect of reclosure. From Table I it will be seen that number one and number two Roanoke–Reusens lines experienced 48 cases of two-line trouble of which 13½ were unsuccessful reclosures during the period from May 1940 to November 1944. The unsuccessful reclosures consisted of 19 cases where only one line of the two failed to reclose successfully and four cases where both lines failed to reclose successfully. An investigation of the large percentage of unsuccessful reclosures experienced on these lines for two-line trouble was made and it was found that apparently cascading of breaker-tripping operations was occurring on these lines which resulted in unsuccessful reclosing operation. At the Reusens end of these lines no source of ground current is available, since the transformer banks are connected delta on the 132,000-volt side and, further, the amount of phase-to-phase short-circuit current available from the Reusens generation is very limited. In some cases of two-line trouble on these lines, both breakers at Roanoke station and only one breaker at Reusens would trip simultaneously on the initial fault and the second breaker at Reusens would trip some eight cycles later after the breakers at Roanoke had opened; this resulted in a dead time of only three to four cycles on one of the lines thus causing a restrike on this line. In some cases both breakers at Roanoke only would open on the initial fault, the Reusens breakers staying in, and would retrip on reclosure due to the arc being maintained by the small amount of generating capacity at Reusens. These operations account for the high number of unsuccessful reclosures on these lines for two-line trouble and further account for the high percentage of unsuccessful reclosures on the total number of two-line trouble operations. The locus for solution of the Roanoke–Reusens line difficulties is obviously beyond the zone of switching and relaying.

The seven unsuccessful reclosing operations for the Saltville–North Bristol and North Bristol–Kingsport lines partially can be accounted for as a result of the systems having drifted so far out of synchronism at the instant of reclosure as to cause the breakers to retrip when low hydroelectric generating capacity is in operation at Waterville. In all seven of these cases all three-phase relays operated at both stations, indicating an apparent three-phase fault; this, however, appears most unlikely on a single-circuit line. The more probable reason for the three-phase relays operating is the interchange of current flow between the two systems at the instant of reclosure on account of the two systems being sufficiently out of synchronism.

Perhaps the most interesting record to note is that of number one and number two Philo–Howard lines which experienced 27 cases of single-line faults and four cases of two-line trouble during the period from May 1940 to November 1944. Here, successful reclosures were obtained in all cases giving the two lines a perfect record for these four years. Before the installation of ultrahigh-speed-reclosing breakers on these lines was made, when two-line trouble occurred it was almost impossible to resynchronize the two systems tied together by them without first dropping load. The installation of ultrahigh-speed-reclosing breakers was thus a perfect solution to the serious difficulty brought about by simultaneous trouble on both circuits.

Conclusions

The data obtained in the course of nine years' experience with ultrarapid reclosure of high-voltage circuits and here presented and analyzed are complete enough to warrant the following definite conclusions:

1. On high-voltage lines, properly insulated and provided with ground-wire protection, 90-per-cent successful reclosure has been and can be obtained by the use of ultrarapid reclosing as now developed.

2. While the experience obtained with double-circuit lines indicates a record of apparently unsuccessful reclosure approximately double that of the average, the significant fact is that in these cases 80 per cent of the apparently unsuccessful reclosure resulted in successful reclosure of one of the two circuits.

3. Ultrarapid reclosure has proved itself a tool of major importance in planning and building any overhead high-voltage transmission system or transmission circuit. It is without question the most economical and reliable means of improving high-voltage-transmission reliability.

4. The confirmed and highly successful result obtained on high- and medium-high-voltage lines again points clearly to benefits obtainable from application to lower-voltage lines. The only barrier to the extension of such application is economic: simpler and lower cost reclosing mechanisms and, if possible, relaying are needed.

5. There is excellent reason to believe that single-circuit, and particularly double-circuit, reclosure performance can be improved by decreasing time of fault duration and thus speeding up the reclosure cycle. The recent successful development of three-cycle breakers,[3] making possible 12-cycle reclosure,[3,4] will open the way for exploring this.

References

1. Five Years' Experience With Ultrahigh-Speed Reclosing of High-Voltage Transmission Lines, Philip Sporn, C. A. Muller. AIEE Transactions, volume 60, 1941, pages 241–6.

2. A High-Capacity High-Voltage Three-Cycle Oil Circuit Breaker, H. L. Byrd, E. B. Rietz. AIEE Transactions, volume 64, 1945, April section, pages 160–3.

3. A Three-Cycle 3,500-Megavolt-Ampere Air-Blast Circuit Breaker for 138,000-Volt Service, H. L. Byrd, B. S. Beall, III. AIEE Transactions, volume 64, 1945, May section, pages 229–32.

4. Field Tests and Performance of Heavy-Duty High-Speed 138-Kv Circuit Breakers—Oil and Air-Blast, Philip Sporn, Harry P. St. Clair. AIEE Transactions, volume 64, 1945.

A Three-Cycle 3,500-Megavolt-Ampere Air-Blast Circuit Breaker for 138,000-Volt Service

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Synopsis: Early investigation of the air-blast principle of arc interruption clearly indicated that this principle was based on sound fundamentals and that continued research and development would lead to an economical and practical design. Preliminary studies indicated that the axial-flow interrupter was admirably suited to the high-voltage breakers with their lower current ratings, while the high current of the low-voltage equipments could be handled best by an interrupter comprising a cross-blast principle. Outdoor axial-blast breakers having interrupting ratings as high as 1,500 megavolt-amperes for service up to 138 kv have been in service for the past few years. Circuit-breaker designers and operating engineers have expended many years of diligent effort in the development of high-voltage oil circuit breakers to their present high degree of dependability and performance. Although the development of high-voltage air-blast breakers is of much more recent origin, the rate of progress has been relatively so rapid that the air-blast breaker described in this paper has exhibited performance characteristics so outstanding as to merit careful attention.

A DISCUSSION of the early field test of a complete high-voltage air-blast circuit breaker developed in this country and tested in the field under actual service conditions was presented before the AIEE in January 1942.[1,2] Two breakers of this design were placed in service at the Turner substation of the Appalachian Electric Power Company in 1942. There are also other installations of outdoor air-blast circuit breakers of similar design but for lower-voltage service, namely 69 and 34.5 kv. These initial installations of outdoor air-blast circuit breakers have verified the sound judgment of the early conclusions regarding the advantages of air-blast interruption, but at the same time have revealed that considerable attention must be paid to the mechanical construction and electrical insulation of outdoor air-blast breakers.

Operating experiences with these breakers have been such as to confirm the following basic desirable qualities characteristic of the air-blast principle:

1. Even at comparatively low pressures, air has a high dielectric strength. Figure 1 shows, graphically, the relative dielectric strength of air and oil for rod gaps having dimensions closely approximating the contact rods used on the air-blast breaker described herein.

2. Air provides an excellent means for transmitting mechanical energy in a device such as a circuit breaker. When used for such purposes, air is the equivalent of an infinitely rugged insulator of high dielectric strength and having practically negligible inertia.

3. Air-blast action, or air flow from a pressure chamber, is extremely effective in carrying away the products of an arc and establishing a space of high dielectric strength in order to effect interruption of an a-c arc.

4. The interrupting time of the air-blast circuit breaker is essentially independent of current magnitude within the range of the breaker rating. The constant interrupting time is explained by the fact that the energy required to interrupt the circuit is stored in the form of high-pressure air in the breaker air receiver and the interrupting time is a function of the mechanical time to release the energy and to move the breaker contacts the required distance.

The operating experience has fully justified the development of a new air-blast breaker for 138-kv service rated 3,500 megavolt-amperes with an interrupting time of three cycles and a reclosing time of 20 cycles measured from the time of energizing trip on the initial short circuit to re-establishment of the circuit.

General Construction of Breaker

Each pole unit consists of the following essential elements with their auxiliaries arranged as shown schematically in Figure 2:

1. Interrupting unit.
2. External switch blade.

Interrupting Unit

Early compressed-air breakers used a jet of air at one terminus of the arc. The air jet was directed around the cylindrical-shaped stationary contact which was partially enclosed in a nozzle-shaped hood. The air exhausted from the nozzle-shaped hood to the atmosphere. The other terminus of the arc was drawn along with the moving contact into an area which was essentially at atmospheric pressure. Since the moving contact was in such a comparatively low-pressure region, it was natural that there should be a pronounced tendency toward progressive electrical breakdown from this point immediately after initial interruption.

The 138-kv air-blast breakers described in references 1 and 3 made use of a construction which permitted the moving contact to remain in a region of pressure approximating 100 pounds. This greatly increased the dielectric strength of the air surrounding the moving contact and consequently increased the efficacy of the earlier air-blast interrupters.

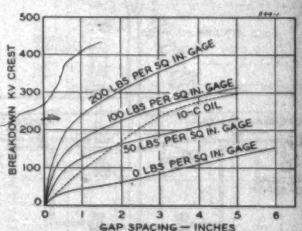

Figure 1. Breakdown of 1 1/4-inch rod gaps in air at various pressures and in oil

The air-blast interrupters developed for the breaker described herein employ a design which:

(*a*). Permits the moving contact to be drawn into the region of maximum pressure and thus assures surrounding air of highest dielectric strength to withstand potential gradient stresses immediately after initial interruption.

(*b*). The air blast is directed in such a manner as to carry the ionized gases generated by the arc away from each contact, thus further improving the ability of the contacts to withstand the high-potential gradient stresses immediately after the initial interruption.

(*c*). Provides excellent voltage distribution across the elements of the interrupter during and after interruption.

A cross section of the entire interrupting unit is shown in Figure 3A. The interrupter has two moving contact rods which complete the electrical circuit through the interrupter by engaging the stationary contact which is located at the center of the assembly. The contact rods normally are held closed under the action of the heavy compression springs shown at upper and lower ends of the assembly. The contact rods are operated

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by pistons which serve to open the contacts against the action of the springs when air is admitted to the interrupter. Each contact moves a distance of eight inches. Each of the stationary contacts is provided with an orifice of slightly smaller diameter than the contact rod tips. These orifices, when uncovered by the opening movement of the contact rods, permit air in the interrupter to be exhausted to the atmosphere.

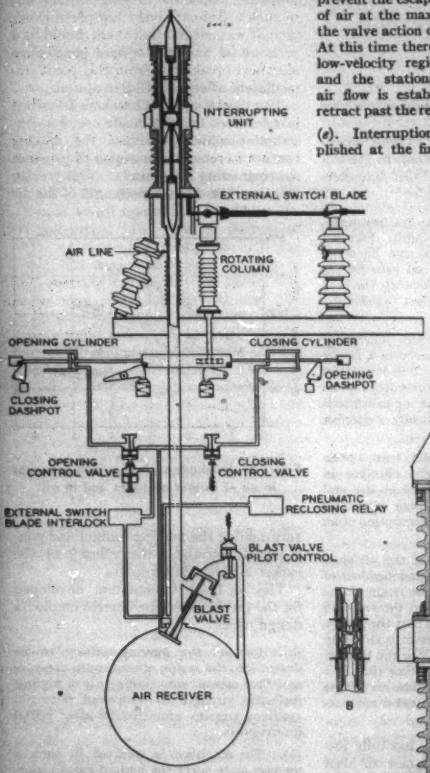
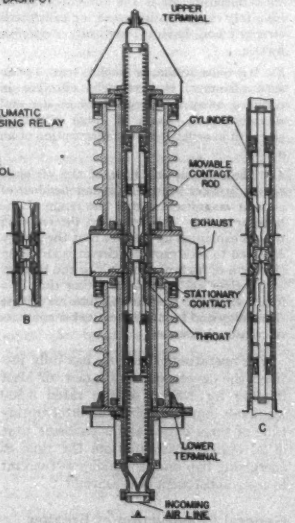


Figure 2 (left). Schematic arrangement of complete pole unit

Figure 3 (below). Sectional view of air-blast interrupter



The sequential operation of the interrupter is as follows:

(*a*). High pressure enters the lower end of the interrupter through the air-line insulator and travels upward through the vertical passages, filling both the upper and lower half of the interrupter.

(*b*). The high-pressure air acts on the pistons to move the contacts apart uncovering the exhaust ports in the stationary contact plates.

(*c*). As the contacts part, an arc is momentarily drawn between the moving contact rod and the stationary contact plate as shown in Figure 3B.

(*d*). The air flow is increased as the contacts leave the throats and, under the action of the air flow carrying the arc products toward a common point, the two arcs transfer from the stationary contacts and establish between the two moving contacts as shown in Figure 3C. During the portion of the stroke in which the contact tips are in the restrictions of the throats, the contacts prevent the escape of the maximum amount of air at the maximum velocity because of the valve action of the contacts themselves. At this time there is a relative low-pressure low-velocity region between the movable and the stationary contacts. Maximum air flow is established when the contacts retract past the restriction in the throats.

(*e*). Interruption is consistently accomplished at the first current zero occurring after the contact rods leave the restriction section of the throats at which time the arc is acted upon by the full force of the air blast.

The interrupting units are controlled by individual blast valves as shown in Figure 2. The valves are of simple construction utilizing pilot control on differential pressure for operation of the main valve. The pilot valve is attached directly to the opening solenoid plunger thus eliminating the necessity of an operating linkage and consequently reducing friction to a minimum. The solenoid, pilot, and main valve have a total operating time of slightly over one cycle. The contacts in the interrupter part in approximately one and one half cycles after the opening solenoid is energized. The contacts reach the end of the restriction in the throats in approximately $2^1/_4$ cycles after the opening solenoid is energized and interruption takes place at the subsequent current zero.

External Switch Blade

The external switch blades are provided for a dual purpose:

1. To maintain the open position of the breaker.
2. To establish the circuit on the closing operation.

The operation of external switch blades is described best from the following description of the sequential operation of the breaker.

Opening Operation

With the breaker in the closed position and with normal air pressure in the air receiver, the trip circuit is set up. The three solenoid coils of the blast-control valves are energized in series initiating the operation of the interrupter units, previously described.

The operation of the external switch blades is interlocked pneumatically to prevent motion of the disconnect unless all three blast valves have operated. The external switch-blade opening valve is pneumatically operated by the interlock and when opened admits air to the opening cylinder. The opening piston drives three racks which engage spur gears attached to the lower end of the rotating insulators, which drive the external switch blade through a beveled-gear arrangement mounted at the hub of the disconnect. When the external switch blades have opened sufficiently to prevent flashover due to system voltage, the trip circuit is de-energized, allowing the interrupter contacts to return to their normally closed position. The typical operation curve, Figure 4A, shows the opening of the interrupter head and the subsequent opening of the external switches after the power circuit has been interrupted.

Closing Operation

During a normal closing operation only the external switch blades are operated. The closing valve coil is energized which opens the valve thus charging the closing cylinder which drives the racks and gears in the direction to rotate the operating porcelain to close the switch blades. The closing time of the breaker is approximately 20 cycles. The design of the external stationary contacts and the switch-contact shoe is such that burning of the current-carrying parts is

almost eliminated and the contact parts will be in a serviceable condition after closing repeatedly 25,000 amperes, the momentary rating of the breaker.

Reclosing Operation

The high-speed reclosing operation is performed by the interrupting heads alone. The blast valves are opened as in a normal trip operation and are immediately closed to allow the interrupter head contacts to reclose and re-establish the power circuit. During the first operation of a reclosing duty cycle, the external switch blades are blocked to prevent motion and the trip circuit is de-energized by means of the pneumatic reclosing relay. The reclosing relay is essentially a pneumatically operated auxiliary switch, the contacts of which control the sequential operation of the reclosing cycle. The reclosing relay is operated by the pressure from the downstream side of the blast valve. By de-energizing the trip circuit at approximately the same time as the interrupter contacts reach their full stroke, the interrupter heads will close to a position where full-line voltage will strike over and re-energize the power circuit through the breaker in approximately 14 cycles. If the fault persists and the trip circuit is again energized, the breaker will go through a normal opening operation. Figure 4B shows a typical no-load reclosing operation with the second trip being energized at approximately 14 cycles.

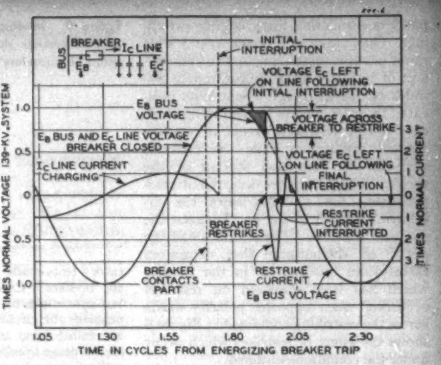


Figure 6. Effect of low-voltage restrikes in breaker-opening capacitance or line-charging currents

Laboratory-Test Results

The results of laboratory and field tests on earlier air-blast breakers[1,3] formed a basis for establishing the laboratory-test procedures employed during the development testing of the new breaker.

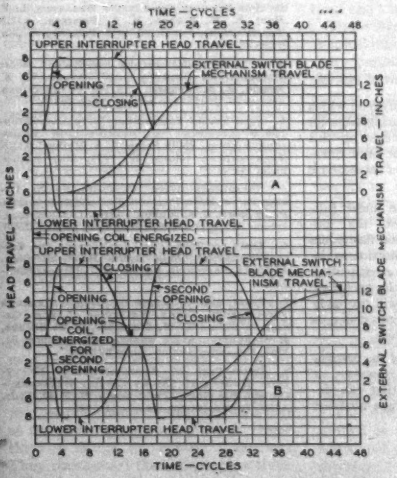


Figure 4. Time–travel curve on interrupter contacts and external switch blade—(A) opening operation and (B) reclosing operation

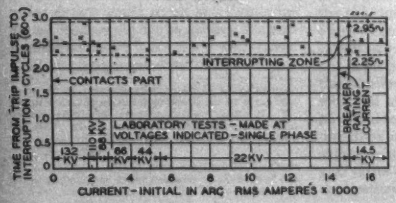


Figure 5. Interrupting performance of breaker during laboratory tests

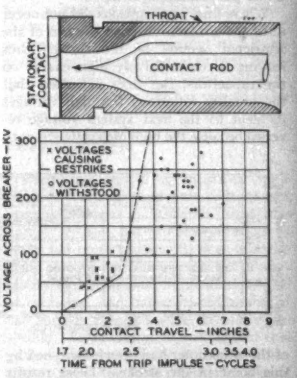


Figure 7. Restrike characteristic of air-blast breaker in opening line-charging current

Figure 5 shows the results of one of the final series of laboratory interrupting tests made prior to shipment of the breaker. It will be noted that the breaker operated with remarkable consistency between the limits of 2.25 to 2.95 cycles corresponding to the first current zero occurring after the contacts leave the constricted section of the throats. This characteristic is one of the primary advantages of interruption by means of an independent source of power. The tests at higher currents were made at reduced voltages. However, it will be noted that the performance of this breaker, in common with other low-arc-voltage interrupters, was essentially independent of the applied test voltage.

The laboratory reclosing tests indicated that the breaker was fully capable of meeting the unusually high-speed reclosing duty for which it was designed. The breaker operated to interrupt all faults within its rating and re-establish the circuit within approximately 14 cycles.

Laboratory tests were made with ca-

pacitors simulating line-charging switching. These tests were made over a wide range of values extending up to an equivalent of 25,500 kva, or approximately 200 miles of 138-kv line. These tests indicated that the breaker evidenced no tendency toward restriking except at very low contact separation while the contacts were in the restricted section of the throat. These restrikes occurred at comparatively low voltages since the dielectric strength of the gap between the contacts was low. The restrikes had the effect of discharging the capacitors rather than building up in the manner which has been observed on restrikes occurring when opposite polarity exists across the restriking contacts.[3,7] Figure 6 shows the effect of restrikes which occur under the conditions outlined.

Where final interruptions did not occur until the contacts reached the end of the restricted section of the throat thus leaving a comparatively high charge on the capacitors, the tests indicated that the breaker withstood the high voltages incident to the next system voltage reversal because the high dielectric strength of the interrupter had been established by this point in the stroke. These results are shown in Figure 7.

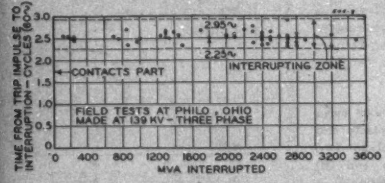


Figure 8. Interrupting performance of breaker during field tests at 138 kv

Field-Test Results

The performance of the breaker during full-scale field tests made at the Philo station of the Ohio Power Company is covered by another paper.[8]

Conclusions

1. The field-test results again confirmed the testing-laboratory procedures. Figure 9 shows a comparison of the breaker interrupting performance on full-scale field tests with results obtained on one series of laboratory tests made just prior to shipment of the breaker. Confirmation of laboratory-test procedures by actual field tests is indispensable to circuit-breaker designers who are called upon to meet the demands for high-voltage breakers of higher interrupting ratings.

2. The precision with which the breaker performed during the entire series of open, closing, and reclosing 138-kv three-phase faults of 260 to 3,500 megavolt-amperes confirms the desirable operating characteristics which have been ascribed to breakers employing an independent source of power for arc interruption. This characteristic of the breaker is shown in Figure 8 on which has been plotted the fault-clearing time for each one of the field tests made on this breaker. The graph shows the fault duration and megavolt-amperes (on three-phase basis) for each pole unit.

3. The reclosing performance under full-power test conditions suggests that deionization time of line-insulator flashovers soon may represent the sole limitation to the speed with which high-voltage circuits may be reclosed.[4,5] The three-cycle operating time of breakers such as this will probably require that we recast our previous concepts on minimum time for deionization.

4. The over-all performance of the breaker has been most gratifying. However, it would be irrational to infer that the developmental task on high-voltage air-blast breakers is completed. Although there are ample data and operating experience on compressed-air systems as used for the performance of purely mechanical operations, use of these data in many cases has been found pernicious where problems of insulation and arc interruption were encountered. More operating experience with high-voltage outdoor air-blast breakers is needed. From the practical viewpoint, more economical solutions to problems of providing adequate current transformers and air-supply systems must be found.

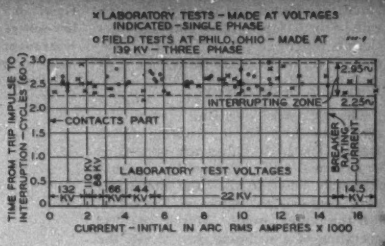


Figure 9. Interrupting performance of breaker, showing composition of laboratory and field tests

References

1. Field Tests and Performance of a High-Speed 138-Kv Air-Blast Circuit Breaker, Philip Sporn, H. E. Strang. AIEE Transactions, volume 61, 1942, January section, pages 1–6.

2. Switching Overvoltage Hazard Eliminated in High-Voltage Oil Circuit Breakers, L. F. Hunt, E. W. Boehne, H. A. Peterson. AIEE Transactions, volume 62, 1943, February section, pages 98–106.

3. A Conserved-Pressure Air-Blast Circuit Breaker for High-Voltage Service, W. K. Rankin, R. M. Bennett. AIEE Transactions, volume 60, 1941, May section, pages 193–7.

4. Five Years' Experience With Ultrahigh-Speed Reclosing of High-Voltage Transmission Lines, Philip Sporn, C. A. Muller. AIEE Transactions, volume 60, 1941, May section, pages 241–6.

5. Experience With Ultrahigh-Speed Reclosing of High-Voltage Transmission Lines. Philip Sporn, C. A. Muller. AIEE Transactions, volume 58, 1939, December section, pages 625–36.

6. Tests on High- and Low-Voltage Oil Circuit Breakers, Philip Sporn, H. P. St. Clair. AIEE Transactions, volume 46, 1927, pages 289–314.

7. Tests and Analysis of Circuit-Breaker Performance When Switching Large Capacitor Banks, T. W. Schroeder, E. W. Boehne, J. W. Butler. AIEE Transactions, volume 61, 1942, November section, pages 831–31.

8. Field Test and Performance of Heavy-Duty High-Speed 138-Kv Circuit Breakers—Oil and Air Blast, Philip Sporn, H. P. St. Clair. AIEE Transactions, volume 64, 1945.

400-Cycle Inverters for Military Aircraft

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Synopsis: Certain equipment on modern military aircraft requires a-c power with a high standard of quality. Good wave shape, very small voltage variations, fairly close frequency range, freedom from radio-noise interference, and reliability over a wide range of operating conditions are required of the power supply. A review of the authors' experiences in design and development of such power supplies is offered with some suggestions for future explorations.

WITH THE ADVENT of World War II, demands for automatic controls, radio, and other types of intricate equipment for military aircraft increased rapidly. In general, this type of equipment requires an a-c power supply having extreme freedom from wave distortion, modulation, and transient disturbances. Nearly all such devices require very close control of voltage, and many require control of frequency to variations of plus or minus five per cent. The main electric system of the airplane consists of 28-volt engine-driven d-c generators and storage batteries. In the parlance of the service laboratories, an inverter is a device for converting d-c power to a-c power and that definition will be used throughout this paper. The purpose of this paper is to point out some of the problems in the design of suitable inverters for such exacting service. Such a discussion would not be complete without a look at the future with some suggestions for improvement by careful co-ordination between designers of airplanes, auxiliary equipment, and auxiliary power supplies.

Standardization of Frequency and Number of Phases

Even after the beginning of hostilities there were conflicting schools of thought regarding the proper frequency and the most desirable number of phases to obtain the lowest weight of the over-all system. Designers of radio and similar equipment proposed an 800-cycle single-phase source as the power supply which would enable them to design the lightest equipment. They maintained that, although a three-phase design would result in a lighter inverter, loads could not be divided to maintain the necessary balance between phases. Another group pointed out that increasing power requirements on larger airplanes indicated an early trend to alternating current as the main power supply with the load predominantly motors. If a two-pole motor is assumed to be the lightest design, this would result in motor speeds far above existing practical limits. Naturally, this group desired three-phase supply because of the resulting savings in weight of both motors and generators. Pressure for standardization and its obvious advantages finally forced agreement to 400-cycle three-phase supply for large systems. However, the problems of balanced loading under all conditions of component-load operation presented such an obstacle to the three-phase system that single phase was soon adopted for most inverters.

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Types of Inverters

There are many devices to obtain alternating current from a d-c source. Among these devices are mechanical vibrators, electronic inverters, dynamotors, motor alternators, and various special combinations and variations of these types.[1]

The vibrator inverter relies on mechanical interruption of the direct current at the desired frequency. Although these devices have given excellent performance on many applications at 60 cycles, higher frequencies are limited because of mechanical difficulties. Such devices have found wide use in aircraft[2] for small power ratings and frequencies below 200 cycles (see Figure 1).

The electronic inverter always has been difficult to apply where the transformation must be effected from a low-voltage high-current source. This is because tube size is largely a function of current and because efficiency decreases with operating voltage as a result of the relatively constant internal voltage drop of the tube. The electronic inverter is inherently unstable and usually requires elaborate control to maintain stability. All these factors have precluded its use on aircraft.

The dynamotor inverter may be described as a d-c motor with taps, or an additional rotor winding, connected to slip rings. A-c power may be drawn from the slip rings. In other words, input and output windings have a common magnetic circuit like a transformer, and voltage output is proportional to voltage input as in the transformer. Control of the field current will change the frequency but will have little effect on the voltage. Since the direct-voltage supply is subject to considerable variation, the output voltage also varies over too wide a range for many applications. This limitation, in addition to the adverse effect of low-power-factor loads on commutation, has prevented very extensive use of the dynamotor inverter on recent military aircraft.

The motor alternator, as its name implies, consists of a d-c driving motor and an alternator which supplies the a-c power output. It is inherently heavier than the dynamotor, but its operating characteristics are much more adaptable to the requirements of aircraft inverters. The separate magnetic circuits provide the maximum isolation of the output from disturbances on the d-c supply system. Independent control of frequency and voltage is easily obtained. Considerable investigation at the outset of development work on aircraft inverters has resulted in the conclusion that the lightest type of alternator is the salient-pole alternator with excitation supplied from the d-c line. Various types of inductor generators and permanent-magnet generators have been investigated; but, for equal output, heating, power factor, and inherent stability, the salient-pole machine has proved to be lighter.

Power Packages

Early inverters were furnished with separate voltage regulators, filters, and starting systems. Demands from the armed services led to incorporation of more and more of these devices into the same structure. The advantages of simplicity of design, ease of installation, ease of servicing, and better co-ordination of the various elements were obviously desirable. Later designs have followed this pattern and have proved very satisfactory. One of the more recent examples of this design philosophy is described in detail.

Frequency Control

Frequency control of vibrator and electronic inverters is not within the scope of this paper. Frequency control of dynamotors and motor alternators is much the same, since both involve the variation of

Figure 1. Vibrator-type inverter

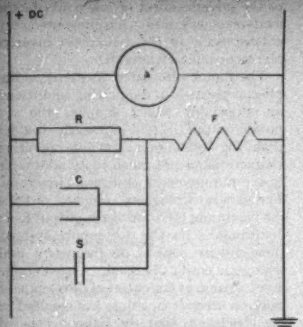

Figure 2. Elementary circuit of centrifugal contact-speed regulator

A—Motor armature
C—Capacitor
F—Motor field
R—Regulator resistor
S—Regulator contacts

the field current to maintain the necessary rotational speed. Of the several methods of frequency control available, none is free from objectionable features. All methods depend on control of the current in one or more field windings of the motor or dynamotor. For success, each method depends on a motor design which is co-ordinated very carefully with the requirements and with the limitations of the control to be used.

One simple light control consists of centrifugally operated contacts in parallel with a fixed resistor. This resistor is placed in series with the motor field (see Figure 2). In the simplest form, this contact remains open until regulating speed is reached, being held open by the leaf spring to which the movable contact is secured. When the control speed is reached, centrifugal force on the contact becomes greater than the spring force, and the contacts close. This allows more field current to flow, reducing the motor speed. As soon as the speed falls to a value such that the spring force again exceeds the centrifugal force, the contacts open again, reducing the field current and increasing the speed. In most cases, speed can be maintained within plus or minus two per cent by this means. However, there is some deterioration of commutation, and some troubles have been experienced with the contacts. A small capacitor usually is required across the contacts to assist in breaking the field current. The wide temperature, voltage, and load variations encountered in such applications require a large difference between the minimum field current and the maximum field current. Therefore, the resistor, *R*, must be a large percentage of the total field-circuit resistance. Operation of the contacts, in effect, shifts the motor back and forth between widely divergent speed-torque curves. The resultant armature current pulsations cause variation in the d-c terminal voltage. This voltage variation is reflected into the alternator excitation, producing an objectionable modulation of the a-c output voltage. Modulation as low as one half of one per cent has caused trouble on some apparatus.

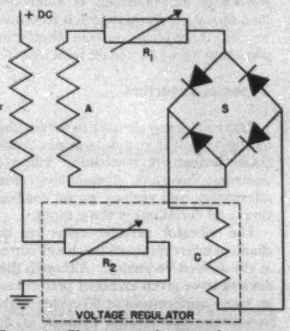

Figure 4. Elementary voltage-regulator circuit

A—Alternator output winding
C—Voltage-regulator actuating coil
F—Alternator field winding
R_1—Calibrating resistor
R_2—Field-control resistor
S—Rectifier

Another basic type of frequency control makes use of a resonant circuit which is supplied from the inverter output. Variation in frequency causes a large change in voltage across one of the elements. This change in voltage may be used directly to vary a control field of the motor, or it may be amplified by one of several means. Without amplification, the elements of the resonant circuit may be quite large and heavy. If amplification be used, either electronic or some other means, the resonant circuit can be small, but the amplifier adds weight. Some work has been done using the resonant circuit with electronic amplification. Amplification also has been accomplished very successfully using a standard aircraft carbon-pile voltage regulator. All of these methods, though giving continuous smooth control, are heavy. In addition, if electronic amplifiers be used, high-voltage fine-wire field windings are required, which introduce additional hazards to reliability.

Another method, which appears to have good possibilities, is the carbon-pile-type speed regulator, which is operated centrifugally. Speed variations are translated into force by a centrifugal mechanism. The force controls resistance of the carbon pile, which in turn controls the motor field current. However, no great amount of operating experience has yet been obtained. It is feared that this device probably will be subject to the same troubles as the carbon-pile voltage regulator, which will be discussed later.

Voltage Control

Early types of d-c regulators for aircraft first were used to control inverter output by rectifying the a-c output and feeding this direct current into the actuating coil of the regulator. Temperature compensation of the circuits was not difficult, but these early regulators consisted of tapped resistors, which were successively short-circuited, tap by tap, to control the alternator field current. Severe modulation difficulties were experienced due to hunting between the nearest taps above and below the voltage actually required to satisfy the actuating coil of the regulator. The device, including the necessary rectifier and temperature compensation, required shock mounting and was considered to be bulky and heavy. A picture of the regulator element is shown in Figure 3.

The carbon-pile voltage regulator has been adopted widely in this country (see Figure 5). It has been adapted to control of inverters, in the same way as the

Figure 3 (left). Early type of tapped-resistor voltage regulator

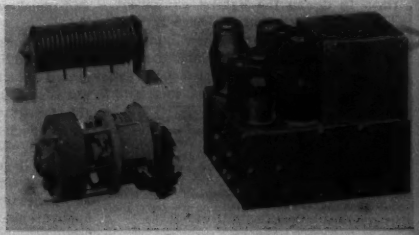

Figure 5 (right). Experimental electronic voltage regulator (American Time Products, Inc.) compared with a carbon-pile voltage regulator (Leland Electric Company) and its rectifier

tapped-resistor type just described (see Figure 4). It has the advantage of continuity of control but requires a high degree of skill to adjust in the field. It is also somewhat unstable, which has caused considerable trouble due to modulation of the output voltage. The good performance of the carbon pile disks under short-time loading conditions provides a temptation to give them a higher service rating than practical, especially in view of the insistent demand for reduced weight. However, the minute arcing which occurs when the pressure is reduced on the disk to secure maximum resistance, causes pitting and cumulative burning, so that the device is soon inoperative if it is overloaded. Only experience can tell what the proper limit of rating these carbon-pile regulators should be. The aforementioned delicate adjustment which must be repeated after the simplest of servicing operations is a considerable hazard to reliable operation.

Some work has been done with electronic control devices (Figure 5), where a bridge circuit compares output voltage with a standard-voltage tube. Output of the bridge circuit is amplified by electronic tubes and fed into a control field of the alternator. Here again, high voltages and fine-wire windings are objectionable from the standpoint of reliability, as compared with other types of control. So far, devices of this type are both heavy and bulky, compared to the carbon-pile type.

Present requirements of certain inverter loads are too severe to be satisfied with any existing regulators. Considerable experience in this field indicates that either regulators must be improved or the load device must be made less sensitive to modulation and voltage variation.

Radio-Noise Requirements

Most equipment is quieted by suitable filters installed on the airplane at the point of manufacture. Since inverters are frequently installed after manufacture and delivery of the airplane to the armed services, they usually are required to meet radio-noise limits. This means that radio-noise filters are built in as part of the machine. Most specifications require standard limits of noise over a standard frequency band, but requirements appear to be increasing in severity at this writing.

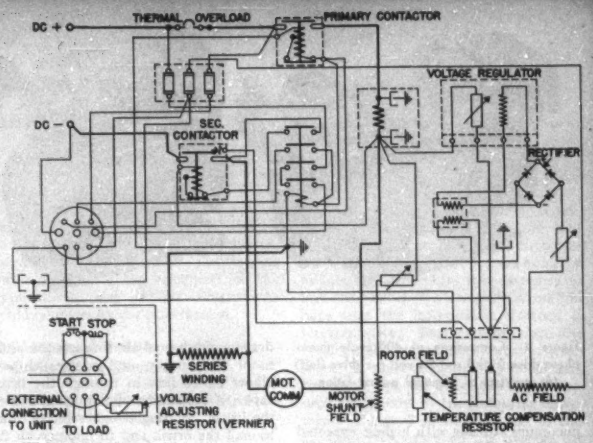

Figure 7. Wiring diagram of inverter

Brush Life

Early d-c motors and inverters for aircraft encountered considerable difficulty because of the extremely short life of the brushes when operating at high altitudes. The reasons for the condition were several. Brushes used on early machines were those selected by designers based on their experience with ground-level performance. At the same time, in their desire to meet pressing demands by the armed services for lighter equipment, compromises occasionally were made with designs which were later proved inadvisable. Finally, the effects of commutation on brushes and commutators at high altitudes where extremely small quantities of moisture are present had not been investigated. This last factor, the most important, required time to prove and longer to overcome. Rapid strides were made to develop brushes suitable for high-altitude operation, once equipment was available for high-altitude testing.[3,4] Radical improvements also have been made in brush cooling, as will be described later.

Cooling

Lightweight high-speed devices for aircraft must dissipate most of their heat by forced convection, because natural convection and radiation cannot dissipate successfully the losses generated in such machines. When altitudes representing one quarter of an atmosphere (approximately 40,000 feet) are encountered, the volume flow of cooling air remains constant, but its weight flow drops to one fourth that obtained at sea level. This means that the ventilating air is much less effective under these conditions. This effect is compensated for, to some degree, by the lower temperatures at such altitudes. Smithsonian tables[5] indicate an average temperature of −55 degrees centigrade at 40,000 feet. However, inverters and similar equipment usually are installed in the main fuselage, and flight tests indicate that the unheated cabin temperature is normally 25 to 35 degrees centigrade warmer than outside air. The designer's problem would be greatly simplified, if more data on operating conditions were known. However, from the data indicated, it readily may be seen that the worst condition for cooling is that of

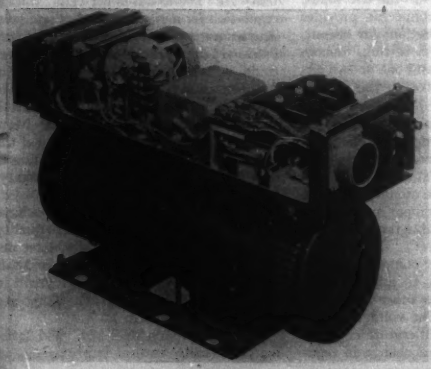

Figure 6. Power-package inverter—1.5 kva, 360/500 cycle

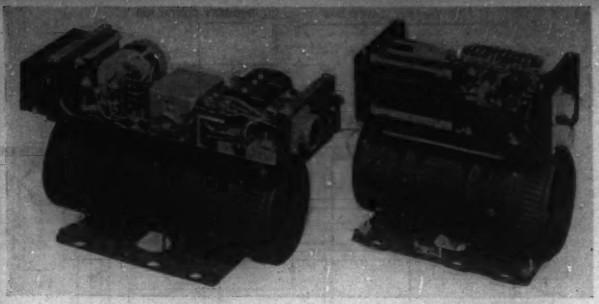

Figure 8. Comparison of 400-cycle three-phase drive (right) and 28-volt d-c drive (left) for inverters of identical output rating

maximum altitude with highest expected machine ambient temperature. Early machines were designed for temperature corresponding to Smithsonian values, which meant that performance suffered when higher ambient temperatures were encountered. Newer designs have taken into account these higher ambient temperatures at high altitudes.

Later machines have been designed to obtain better cooling of the brushes and, at the same time, maintain adequate cooling of the windings.

Maintenance

Because of misconceptions of expected service procedures and requirements, many early designs did not give sufficient emphasis to ease of servicing the equipment. This shortcoming, combined with the short brush life mentioned, resulted in vigorous complaints by service personnel. Later designs have been improved vastly in this regard, particularly with respect to brush inspection and replacement.

Typical Inverter

A recent design which has been used widely in Army aircraft is shown in Figure 6. An interesting feature of this inverter is that all structural parts, with a few exceptions, are of steel. This feature was dictated by the extreme shortage of aluminum and magnesium at the time of its development. By careful design, an over-all weight penalty of only five per cent was involved.

The right-hand side of the machine, as viewed in Figure 6, is the drive motor. Brushes may be removed for inspection without the use of any tools and can be replaced with new brushes by a few turns of one screw on each stud. The removable brush caps are part of a carefully designed cooling system for the brushes. The fan expels air from the machine, drawing fresh cool air through the alternator and motor, and a parallel path allows air to flow in through the brush caps. A restriction of flow occurs along the brush, creating a high velocity of air to cool the brush and to impinge on the commutator surface for further cooling benefits. This system has greatly increased brush life without resorting to reduced current density in the brushes. This factor, coupled with improved brush materials and improved commutation, resulted in high-altitude brush life which was startling compared to previous experience. The brush life of this machine far exceeded any obtained previously. Recent improvements on drive motors for other types of equipment, where duty is not so severe and where the same basic type of brush rigging and cooling is used, indicate an expected high-altitude brush life equal to or better than that expected at normal altitude.

The left-hand side of the machine consists of the alternator. The wave shape is extremely good, having a harmonic content below four per cent. It consists of a six-pole salient-pole rotor excited through slip rings from the d-c supply. The 400-cycle output is generated in the stator windings.

The control box is mounted on top with heavy stud terminals for the d-c input. A standard aircraft connector provides easily removable connections for output, remote vernier voltage setting, remote push-button starting, and one or two circuits not directly related to this discussion.

If viewed from left to right, the control box includes voltage regulator elements, radio-noise filter, contactors, and interlock relay for motor starting. All elements of the control are mounted for ease in servicing and replacement in the event of combat damage. A diagram of the circuit is shown in Figure 7. Provision is made for temperature compensation of the motor field circuit to minimize frequency variation. No other frequency control is provided. The voltage-regulator network is also temperature compensated. Tests indicate a change in regulated voltage of less than one volt over a range of −40 degrees centigrade to +65 degrees centigrade.

This machine, though made obsolete by more recent armed service specifications requiring closer frequency limits, still represents many desirable features for this type of equipment. With the addition of frequency control with a suitable driving motor, it would conform closely to present-day specifications for future applications.

It represents a partial retreat from the extreme "bone cutting" weight reduction of earlier designs. It has operated continuously at altitudes above 35,000 feet at ambient temperatures of +15 degrees centigrade for long periods of time. With increasing experience regarding types of installation, it is believed that the margin of safety in this machine, though much greater than foregoing designs, is none too great. Since these inverters usually are installed after all other equipment, compromises made with ventilation upon installation are frequently startling.

For future applications on aircraft with a-c power supplies, it may still be necessary to isolate certain fussy loads from the main system. Figure 8 shows an interesting comparison between two machines designed to identical specifications, except that the drive motor for the machine on the right is designed to operate on a 400-cycle, three-phase supply while the machine on the left is identical to that in Figure 6, for d-c supply. The simplification of control and weight reduction are quite obvious.

Recommendations

In view of the considerable weight required for control, it appears reasonable to suggest a review of present specification limits with the following points in mind.

Inherent speed regulation without the use of speed-control devices appears to be limited to about plus or minus ten per cent. Current developments in permanent-magnet excitation indicate a possibility of five-to-seven-per-cent voltage regulation for a given frequency and voltage proportional to frequency for any fixed load impedance. If the load devices could be designed for such a spread in frequency and voltage with less increase in weight than that saved in the control, over-all weight would be reduced. More important, much of the complexity of the inverter would be eliminated, resulting in less field servicing, greater dependability, and longer life.

In general, new electronic devices have been very demanding in regard to quality of the power supply. Usually, later designs can tolerate more variation, and this trend should be encouraged, if it result in lower over-all weight, greater simplicity of the system, or both.

If this approach does not yield satisfactory results, radical improvement in

An Interval Timer for Arc Duration

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IN DEVELOPMENT work leading to new and improved designs of equipment involving arc interruption the success of the work is to a large extent influenced by the quality of the instruments used for measurement. The arc-interruption problem is one that has been in existence since the first electric installation. Nevertheless, progress continually is being made in developing smaller and more efficient devices for stopping the flow of electric current. One of the most promising ways of furthering this progress lies in the development of new methods of measurement.

Scope of This Paper

This paper describes a laboratory electronic instrument which was developed for the purpose of measuring in milliseconds the time during which arcing exists when an electric circuit is opened. The need for such an instrument and the type of investigation for which it is best suited also are discussed. Examples are presented to illustrate the usefulness of the instrument for timing both a-c and d-c arcs.

The interruption devices referred to in this paper are those commonly found in industrial-control applications: contactors, relays, push buttons, and so forth. In some respects the problem of arc interruption for control applications is similar to that found in switchgear and other related applications. The illustrations given will be, for the most part, on a-c applications, but similar illustrations could be given for d-c interruption.

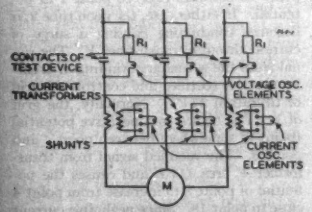

Figure 1. Circuit-connection elementary diagram for a three-phase arc-interruption test, showing connections for magnetic-oscillograph elements to record current and voltage traces for each phase

M—Locked-rotor motor load

Development Testing on Arc-Interrupting Devices

Arcing tests on industrial-control devices can be classified as

1. Interruption tests.
2. Life tests on the contact tips.

The two are somewhat interrelated. Because it takes several months to conduct a single tip-life test, some means of predicting the outcome of these tests is essential, and, in many cases, the interruption tests serve this purpose.

Interruption tests sometimes are made in order to determine whether a device will interrupt a particular load, but more often they are made to compare designs and to find out which is the most efficient. The tests consist of operating the contactor making and breaking the current of a prescribed load. A locked-rotor motor frequently is used for load, because, in general, it is the most severe load that the contactor will be required to interrupt. The arc-interruption transient usually lasts 50 milliseconds or less for a-c applications and 100 milliseconds or less for d-c applications. There is little commercially available measuring equipment that will measure during so short an interval.

Measuring Equipment

The magnetic oscillograph frequently is used to obtain arc-interruption information. The circuit connections used for this purpose are shown in Figure 1. The current and voltage traces for one phase resulting when the contactor is closed and opened, are shown in Figure 2. Elements may also be used to record arc-energy traces, or the energy may be calculated for each interruption from the voltage and current traces. The information obtained from an oscillogram, then, is the arc time in milliseconds, the wave-shape of the arc voltage and current, and the arc energy.

It is not feasible to take oscillograms of all operations, because an interruption test may consist of several hundred operations. Even if the records were taken and developed, the time required to transcribe the information from them would be prohibitive. Therefore, it is necessary to base conclusions on a few oscillograms and hope that the information obtained is representative. Furthermore, since the oscillograph element and its external resistor, R_1, must be placed in parallel with the arcing tips, the quantities to be measured are affected by the measuring equipment. Figure 3 shows the effect of this arc-shunt resistance on the average arc time. The oscillograph circuit resistance shunting the arc usually ranges between 5,000 and 15,000 ohms for 550-volt interruption. The average arc time is 70 to 90 per cent shorter when the oscillograph is connected, the data recorded on oscillograms being optimistic. It would be impractical to use a more sensitive oscillograph element because of its limitations of frequency response.

Information on arcing can be obtained by means of high-speed moving pictures. In some cases the information obtained is excellent, but in analyzing the results obtained the modifications that were necessary so that the arc could be photographed should be kept in mind. A fact not well known about this technique is that, if an auxiliary light source is used, the amount of light required for the high-speed pictures may obscure the arc on low-current interruptions for several milliseconds both at the beginning and at the end of the arcing period. The expense and time required to obtain data are additional limitations of this method.

An instrument has been developed to measure the arcing time for d-c interruptions as well as the time of bounce of contacts when closing.[1] With this instrument the contacts under observation can be tested only on direct current. Concerning a-c interruption, the paper describing the instrument states that, because of the additional variables involved, readings of arc time will vary widely. The article continues "If the test is made with direct current, the latter can be adjusted to any value, thus simulating any desired 'instantaneous' value of alternat-

devices for the control of frequency and voltage is needed. The prime requirements of such devices are light weight and continuity of control. In other words, discontinuities, such as finite resistance steps or vibrating contacts, should be avoided.

References

1. AIRCRAFT INVERTER CONSTRUCTION, C. T. Button. AIEE TRANSACTIONS, volume 62, 1943, September section, pages 598–602.

2. AIRCRAFT TRANSFORMERS—SMALL AND LIGHT, O. Kiltie. AIEE TRANSACTIONS, volume 62, 1943, pages 899–902.

3. THE TESTING OF BRUSHES FOR LIFE AND PERFORMANCE UNDER VARIOUS ALTITUDE CONDITIONS, C. J. Herman. AIEE TRANSACTIONS, volume 63, 1944, December section, pages 929–33.

4. NEW TEST CHAMBERS FOR AIRCRAFT ELECTRIC APPARATUS WITH PARTICULAR REFERENCE TO CARBON BRUSHES, E. R. Summers, J. F. Settle. AIEE TRANSACTIONS, volume 63, 1944, pages 1206–12.

5. SMITHSONIAN PHYSICAL TABLES (book), eighth edition. Smithsonian Institution, Washington, D. C., 1934. Table 695.

Paper 45-64, recommended by the AIEE committee on instruments and measurements for presentation at the AIEE winter technical meeting, New York, N. Y., January 22–26, 1945. Manuscript submitted November 14, 1944; made available for printing December 28, 1944.

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Figure 2. Oscillograph traces of voltage and current transients produced during a single-phase arc interruption

The E_s signal is the voltage signal from across the contacts of the interrupting device while the E_t signal is proportional to the interrupted current

ing current." Actually, a-c interrupters are seldom tested on direct current, since the interruption phenomena involved are quite different. The fact that arcing time varies over a wide range emphasizes the need for some means of easily obtaining a large number of readings to insure proper analysis.

The Electronic Arc Timer

A laboratory electronic instrument for measuring the length of time that an arc persists when an electric circuit is opened has been developed. The instrument requires two input signals, one obtained from the arc voltage, and the second from the circuit current. Typical arc-voltage and circuit-current signals are shown on Figure 2. Timing is initiated when the voltage signal appears, and it is stopped when the current goes to zero. During the interim, a capacitor is charged linearly with time, and the voltage on the capacitor is inversely proportional to the arc time. The instrument consists of a regulated power supply, a timing circuit, a voltage-signal circuit, and a current-signal circuit. These circuits are shown on Figures 4, 5, 6, and 7 which are drawn so that the position of a line on a diagram is indicative of the potential of the element represented. Point 5 is at the lowest potential and is drawn at the lowest position on the circuit diagram, whereas point 1 is at the highest potential and is drawn at the top of the circuit diagram. This method of drawing the diagrams should be kept in mind for the following explanation of the operation of the instrument.

The power supply and timing circuit are shown in Figure 4. The power supply is of the conventional type used to provide constant direct voltages independent of a-c line voltage fluctuations. The timing circuit consists of capacitor $3C$ charged by a constant current through pentode $9VT$. The charging current is controlled by the variable cathode resistor $5VAR$. The maximum time interval measured can be varied either by changing the size of the capacitor $3C$, or by changing the charging current. The voltage across the timing capacitor $3C$ controls the grid of a cathode-follower circuit in which a d-c voltmeter is used as the cathode resistor. The voltage across the voltmeter is therefore inversely proportional to the voltage on the capacitor. This unique method of measuring the voltage across the capacitor reduces the leakage current to a minimum. The timing circuit is turned on and off by means of the bias voltage that is placed on the screen-grid of the pentode at point 7. The following is an explanation of how the arc voltage and circuit current are used to start and stop the timing circuit.

The voltage-signal circuit that starts the timing circuit is shown in Figure 5. E_s and C are connected across the tips of the device on which the arc time is to be measured. When the tips of the test device are closed, current is flowing through the tips, but the voltage across them is practically zero. With zero voltage between E_s and C, point 16 (plate of $17VT$) is adjusted by means of the potentiometer

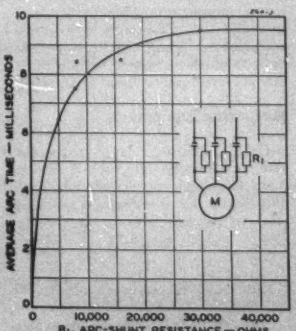

Figure 3. Average arc time versus arc-shunt resistance for arc interruption by a commercially available size-2 contactor

100 readings of arc time taken for each point. One third of readings taken on each phase

M—550-volt 305-ampere 50-horsepower locked-rotor induction motor

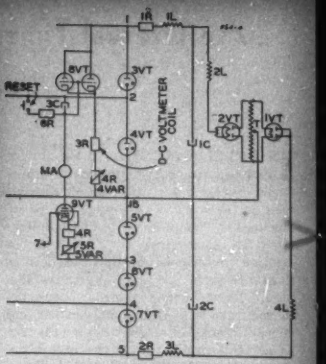

Figure 4. Power supply and timing circuit for arc-interval timer

$3VAR$ to the level of point 2 in potential. As soon as the contacts part and arcing begins, a voltage appears between E_s and C. E_s may be either positive or negative with respect to C. The change in potential between point 10 and point 4 is proportional to the change between E_s and C. Point 10 controls the potential of point 16, which controls the current through the peaking transformer V. If E_s becomes more than five-volts positive with respect to C, point 16 drops close to point 18 in potential. When E_s becomes more than five-volts negative with respect to C, point 16 becomes close to point 1 in potential. In either case, the neon tube $2Ne$ becomes conducting causing a surge of current through transformer V. The signal from the secondary winding of transformer V is rectified and controls the grid of thyratron $11VT$. Normally, the grid of $11VT$ is biased to a negative potential (point 9) somewhere between point 4 and point 5. The rectified signal from transformer V fires $11VT$ and causes the potential of point 8 to increase from point 4 close to point 18. Since negligible current passes through resistor $7R$, point 7 is maintained at the same potential as point 8. Therefore, if a positive or negative voltage signal of five volts or more is placed between E_s and C, the pentode ($9VT$) in the timing circuit is made conducting.

The current-signal circuit that stops the timing circuit is shown in Figure 6. The input signal, proportional to current, is placed between E_t and C. With zero signal input, $1VAR$ and $2VAR$ are adjusted so that $13VT$ and $14VT$ are not conducting, but, if either point 14 or point 15 increases in potential, $13VT$ or $14VT$ will start conducting. With the contacts of the test device closed, E_t is fluctuating with respect to point C. When E_t is five volts or more positive with respect to C, point 12 is close to point 18 in potential, and point 13 is close to point 1

in potential. When E_t is negative with respect to point C, the reverse is true. Therefore, when the current signal is oscillating, points 12, 13, 14, and 15 also are oscillating. Thyratrons $13VT$ and $14VT$ are alternately conducting. When either tube is conducting, point 11 is close to

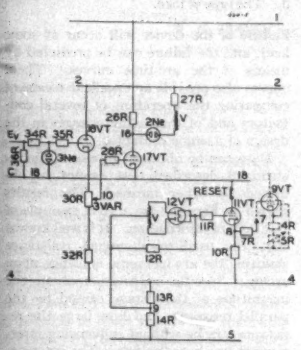

Figure 5. Voltage signal circuit for arc-interval timer

This circuit starts the timing circuit when a voltage is placed between E_t and C

point 18 in potential. During the interim in which neither tube is conducting, point 11 is held down in potential by means of the capacitor $4C$. When the current signal between E_t and C goes to zero and remains zero for a short time, point 11 will increase in potential enough to cause neon tube $1Ne$ to become conducting which results in a surge of current through transformer I. The resulting signal from the secondary winding of transformer I is rectified by $10VT$ and controls the grid of thyratron $12VT$. Normally, the grid of $12VT$ is biased negatively. The rectified signal from transformer I fires $12VT$ and thereby removes the positive bias on the grid of pentode $9VT$ and prevents it from conducting.

The complete circuit for the timer is shown in Figure 7. E_s, C, and E_t are connected to the test contactor as shown on Figure 8. The current signal can be obtained from a small amount of series resistance or from current transformers. With Figure 7 as reference, the operation of the circuit can be summarized as follows. When a voltage signal appears between E_s and C, thyratron $11VT$ is made to conduct. This increases the potential of point 7 and starts the timing circuit. When the signal between E_t and C goes to zero and remains zero for a short interval, $12VT$ is made conducting. This removes the positive voltage from point 7 and stops the timing circuit. The methods of resetting the timer and means of calibrating are given in the following paragraphs.

Reset

Before each reading the timer must be reset while the contacts of the test device are closed and current is flowing. The reset consists of removing the plate voltage from the thyratrons and discharging the timing capacitor. A small relay is used for this purpose. Reset may be accomplished by hand, by means of an external reset, or automatically. When hand reset is used, the procedure is as follows:

1. Close the contacts of the device being tested.
2. Close and open the contacts of the reset relay.
3. Open the contacts of the test device.
4. Read the output voltmeter.

In many cases this process is too slow, and it is not desirable to have current flowing into the load for the length of time required for hand reset. In this case an external relay can be used to reset the instrument. This relay should have two sets of contacts, one of which closes before the second. When this relay is energized, the first contacts to close energize the test contactor and the second reset the timer. When the relay is de-energized, the reset relay is de-energized before the coil of the contactor. This method insures the proper sequencing of events and permits having the test contactor closed for only a few cycles. The third method of reset requires no external relay. The timer is normally held in reset. When the current signal appears, the timer is dropped out of reset, and it is again reset after a definite time delay. The time delay can be adjusted to allow for the operation of the test contactor and for reading the output voltmeter.

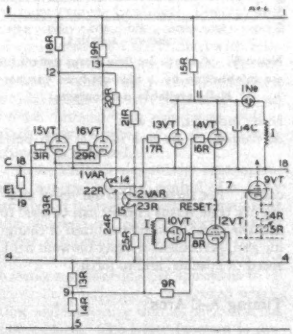

Figure 6. Current-signal circuit for arc-interval timer

This circuit stops the timing circuit when the voltage between E_t and C, proportional to current, goes to zero

Figure 7. Complete circuit diagram for arc-interval timer

Calibration

The arc timer can be calibrated by several methods. Two voltage signals are required for calibration; one to start and the second to stop the timing. If the time interval between the voltage signals can be controlled accurately, a calibration curve of time interval between these two voltage signals versus voltage to which the timing capacitor is charged can be obtained. The voltage signals can be obtained from an electronic circuit or from motor-driven commutators. In the first case the time can be varied by changing the frequency standard, whereas in the second case, the speed of the motor controls the time interval. Calibration also can be accomplished by taking an oscillographic record of an actual arc interruption. Here the timer-output-voltage trace can be put on the same film with the arc voltage and circuit current. From such a record the slope of the timer output voltage in volts per millisecond can be obtained. The time delay caused by the capacitor $4C$ can be measured. By checking a few points in this manner, a complete calibration curve can be obtained. Although the timer possibly could be made into a precision instrument, for arc-interruption work this is not necessary. For

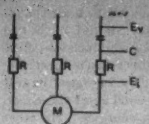

Figure 8. Elementary diagram showing how input signals for the arc-interval timer actually are obtained

M—Locked-rotor motor load

this application, one is interested primarily in comparative results. For this reason, an accuracy of plus or minus one millisecond has been considered satisfactory.

Advantages of the Timer

There are a number of characteristics of the timer that make it well suited for arc-interruption work. It reads directly and thereby eliminates expensive and time-consuming photographic processes. Only a few minutes are required to set up the instrument for a test, and no readjustments are required when the voltage or current to be interrupted is changed, providing the input signals are greater than the minimum five volts. Readings of arc time can be obtained very rapidly, and it requires only a few minutes to complete a test of 100 interruptions with the arc time recorded for each operation. Because its input impedance is several megohms, the timer does not alter the interruption transient. The instrument can be used to time either a-c or d-c interruptions, a feature that distinguishes it from any other device so far reported.

The usefulness of the timer is not limited to the measurement of arc time. It can be used to measure the interval between two voltage signals; either signal can be above five volts and suddenly go to zero or be zero and jump to five volts or more. In this manner the timer has been used to measure the opening and closing travel time of contactors, the sequencing of devices, and for many similar applications. It is especially useful in the range from several milliseconds to 200 milliseconds.

Timing D-C Arcs

The arc-interval timer has been used to advantage for the investigation of d-c arc-interruption phenomena.[3] When a number of interruptions of the same d-c load are repeated the range of arc-time readings usually is not large. For this reason 10 or 20 readings of arc time at each load insure good distribution curves.

A series blowout-type contactor often is used to handle d-c power loads. In these contactors the arc is transferred from the tips to arcing horns soon after the tips part. Figure 9 shows a curve of average arc time versus current for interruption by this type of contactor. The long arc time in the low-current region and the practically constant time for loads above 100 amperes are characteristic of d-c blowout contactors. It should be noticed in Figure 9 that the series blowout field of the usual number of turns is not effective for low currents. For this reason low-current relays and interlocks for control circuits usually do not have a series blowout coil, but rely upon gap or a permanent-magnet field to stretch the arc until the current

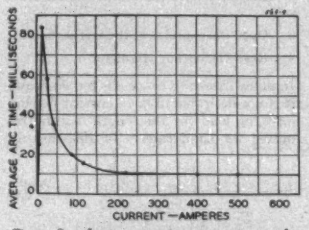

Figure 9. Average arc time versus current for arc interruption by a blowout-type commercially available d-c contactor

Load: inductive, 250 volts
30 readings of arc time taken at each point

ceases. For these devices curves of average arc time versus current can be used to find the effect upon interruption of changing gap, permanent-magnet blowout field, speed of opening, and so forth.

Timing A-C Arcs

The range of arc-time readings for a-c interruption is much greater than for d-c interruption. The principal reason for the difference is that alternating current goes to zero two times each cycle. Interruption occurs at or near the normal current zero. The arc time therefore depends upon

1. The time between the parting of the tips and the following current zero.
2. Which current zero after the parting of the tips completes the interruption.

Because of the large range of readings and because data on arc time must be taken from each of three phases, it is often necessary to take as many as 100 readings at each load.

It is difficult to generalize concerning a-c interruptors, for they are quite different in design and principle of operation. The average arc time is about four milliseconds for loads on which interruption always occurs at the first current zero after the parting of the tips, providing the tips part at random.[3] For larger loads the shape of the arc-time-versus-current curve depends primarily upon

1. The design of the interrupting device.
2. The applied voltage.
3. The type of load.

Failure of the device will occur at some load, and the failure can be predicted by means of the arc-time curves. These curves also provide an excellent means of comparing the operation of several contactors and of evaluating changes in the design of a single contactor.

Data can be obtained by use of the instrument described that cannot be obtained by other means.[3] The results shown on Figure 3 are a good example of this type of information. It is well known that the oscillograph-circuit resistance shunting the arc has some influence upon arcing. Specific information about the magnitude of the change caused by the parallel resistance and how large the resistance can be without influencing interruption has been lacking. The information in Figure 3 was obtained in a few hours.

Conclusion

There has been a definite need for measuring instruments that can supply information concerning the transient produced by circuit interruption. An instrument is described that is especially suited for the measurement of the length of time that an arc-transient exists. The new instrument has been a valuable aid in conducting both a-c and d-c arc-interruption studies. The instrument has been in use for approximately a year, during which time over a quarter of a million readings of arc time have been taken. Data are being accumulated on the performance of interrupting devices, the relative severity of loads, the correlation of single-phase and three-phase interruption tests, and on many other aspects of the interruption problem. This kind of information is of great value to designers of arc-interrupting devices.

References

1. An Instrument for the Determination of Contact Making and Breaking Time, W. Richter, W. H. Elliott. AIEE Transactions, volume 62, 1943, January section, pages 14–16.

2. D-C Arc Interruption for Aircraft, J. S. Quill, L. T. Rader. AIEE Transactions, volume 63, 1944, December section, pages 883–8.

3. Measuring Arc Duration, J. S. Quill. *General Electric Review*, volume 47, November 1944, pages 22–4.

The Combination of Supervisory Control With Other Functions on Power-Line Carrier Channels

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THE PRACTICE of using a single power-line carrier channel to perform several different functions is becoming increasingly common. This practice is encouraged by the savings in equipment and in carrier-channel space that can be effected when a single carrier transmitter and receiver are used jointly by some combination of relaying, telemetering, communication, load control, and supervisory-control equipment. The recent introduction of a wide line of individual rack-mounted carrier components[1] makes it possible to select exactly the apparatus necessary for the combination of functions to be performed and further encourages the use of a single carrier assembly for several co-ordinated functions.

Certain combinations of functions on carrier channels have been described in previous papers.[1,2] These papers generally have described functions on point-to-point channels and have considered mainly such functions as relaying, communication, and telemetering, mentioning supervisory control only briefly. As a result, methods of combining carrier communication and relaying are relatively well known. The channel requirements of telemetering and load control are comparatively simple, and the combination of these functions with others offers no especially difficult problems. However, the channel requirements of supervisory-control systems, particularly those of the multistation type, are relatively more strict than those for most functions. The application of such systems in combination with other carrier functions requires an understanding of these requirements if correct and dependable operation is to be secured. These requirements have not been previously described in detail.

It is the purpose of this paper to point out what conditions must be satisfied for proper operation of a standard supervisory-control system; to tell why some combinations of carrier supervisory control with other functions, which on the surface appear workable, may be subject to undesirable limitations; and to describe methods of co-ordinating certain acceptable combinations so that reliable operation of the supervisory-control system is assured.

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Principles of Operation of Supervisory Control

Supervisory control is a system of controlling and supervising from a central point the operation of equipment at one or more remote locations. Control and supervision of a number of separate pieces of equipment are accomplished with relatively few conductors or channels. In the Visicode supervisory-control system, which is the system considered in all further discussion in this paper, only a single pair of wires or a single carrier channel is required.

In the Visicode supervisory-control system, supervision and control of a large number of individual pieces of equipment are obtained by selective relay systems, which automatically generate and receive impulses in coded groups to perform the functions of selecting the apparatus to be controlled, performing the desired operation, and indicating that an operation has taken place. The latter function is performed whether the operation is initiated through the supervisory system or not.

In this system, a group of units to be controlled is assigned a group number. Individual units within the group are assigned point numbers. These numbers represent the number of impulses in the two series of impulses which must be sent from the dispatching point to select the group and point desired. Selection is accomplished by a system somewhat similar to an all-relay automatic-telephone system, with the following two main exceptions:

1. The operator does not operate a telephone dial to select the remote unit he desires to control. Each remote unit has its corresponding selection button on the operator's control board, and the operator merely depresses the proper button momentarily. The proper group and point selection impulses are sent automatically.

2. After each set of impulses is sent, the receiving equipment at the remote location must send back the same number of impulses before operation can proceed. This provides a positive check at each step of the sequence of operation.

For a complete control operation, the operator presses a point-selection button. The dispatching equipment automatically sends a series of impulses corresponding to the desired group number. The supervisory equipment at the remote station sends back a series of impulses called the group check code, indicating that correct group selection has been made. Reception of the group check code at the controlling point causes the point selection code to be sent. This code also is repeated by the receiving equipment, and the reception of this point check code at the controlling point lights an indicating lamp to signify that the desired unit has been selected and that the remote supervisory equipment is ready to perform a controlling function on that unit. The operator then turns a two-position twist key to the desired operation, for example, to "trip" if a circuit breaker is being controlled. This lights a "disagreement" lamp, indicating that the condition of the controlled equipment does not correspond to that indicated by the position of the twist key. The operator then presses momentarily another button, which causes his

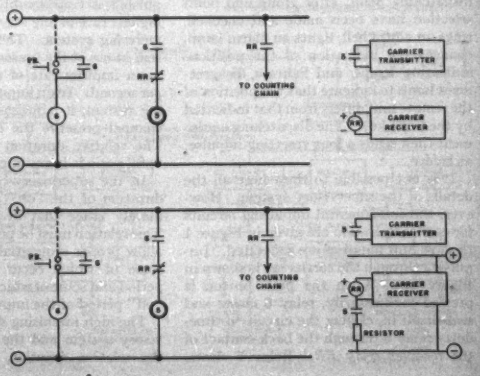

Figure 1. Fundamental supervisory-control impulsing circuits for carrier operation

A (above). External stepping

B (right). Internal stepping

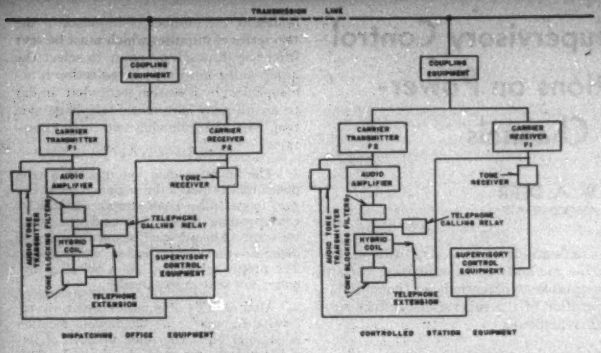

Figure 2. Block diagram showing essential components for combination of point-to-point two-frequency duplex carrier communication with single-station supervisory control

supervisory equipment to send a third series of impulses. These impulses, when received at the remote station, cause the supervisory equipment to close the necessary circuits to perform the desired operation. Operation of the controlled equipment in the desired manner then causes the remote supervisory apparatus to send back the "supervision" code. Reception of this code at the controlling point changes the indication of the red and green position-indicating lamps and extinguishes the disagreement lamp. The supervisory equipment at the controlling point then automatically sends a long impulse which resets the entire supervisory system to normal.

Operation of the supervisory system to indicate an automatic operation of controlled equipment at a remote point is somewhat similar, except that group- and point-selection codes automatically are initiated from the remote point and checked back from the dispatching point. Reception of the supervision code at the dispatching point, after group and point selection have been made and checked, rings an alarm bell, lights an alarm lamp, changes the indication of the position-indicating lamps, and lights a disagreement lamp to indicate that the position of the remote unit differs from that indicated by the twist key. The dispatching equipment then sends a long resetting impulse, as before.

It is not possible to show here all the details of the supervisory system. However, the fundamental impulsing circuits for carrier operation are given in Figure 1 to show how impulses are generated. Impulsing through the carrier set is shown in Figure 1A. When the push button is pressed momentarily, relay 6 closes and seals itself in, closing the circuit to time-delay relay 5 through the back contact of the receiver relay *RR*. Relay 5 closes, starting the carrier transmitter. Reception of the transmitter by the local receiver causes relay *RR* to operate, opening the circuit to relay 5. After a slight time delay, relay 5 releases. This cycle of operation constitutes one impulse. Impulsing continues automatically until proper number of impulses for the desired group are sent, whereupon counting relays open the circuit to relay 6 through contacts not shown. This stops impulsing and prepares the equipment for reception of the check-back code. This type of impulsing is called external stepping.

It is possible in some cases to operate the receiver relay directly from the carrier power source by placing an additional contact of relay 5, in series with a suitable dropping resistor, across the plate circuit of the receiver detector. Impulsing then can take place, even though the transmitted signal is not received locally. This is called internal stepping.

Channel Requirements of Supervisory-Control Systems

The rate of impulsing of the supervisory equipment is from 9 to 14 impulses per second, comparable to the speed of impulsing of a telephone dial. This rate of impulsing is considerably higher than the highest rate of any standard impulse telemetering system. The fastest such system in use at the present time has a maximum impulse rate of approximately 3.5 per second. In an impulse-rate telemetering system, it is necessary only that the channel preserve the rate of impulsing. The relative duration of the "on" and "off" periods is not important.

In the supervisory-control system the duration of the "on" period is approximately twice that of the "off" period. This relation must be preserved in order to allow proper sequential relay operations, some of which occur during the "on" period and some of which occur during the "off" period of the impulse cycle.

The high impulsing speed of the supervisory system and the requirement that the relative duration of the "on" and "off" periods be preserved make it undesirable to use more than one relaying point to retransmit mechanically supervisory impulses received from a distant point.

When the supervisory system operates on an audio-frequency tone channel modulating a carrier transmitter, the tone frequency and the speed of operation of the tone receiver must be such that the supervisory impulses can be handled without appreciable distortion of the "on" and "off" periods. In the line of tone equipment described in reference 1, a number of tones suitable for supervisory operation are available. This makes it possible to combine supervisory control with telephone communication, with suitable filters to prevent interference between the two functions. The filters are inserted into the speech circuits and eliminate the supervisory tone frequency from the speech frequencies transmitted.

There are two types of Visicode supervisory control, one in which all the equipment to be controlled is located at a single point, and one in which the equipment is in several groups at different locations. These two types are referred to as the single-station and multistation systems, respectively.

A fundamental requirement of the multistation system is that a control or supervision function in progress between the dispatching office and a controlled station should not be interfered with by supervisory signals from other controlled stations. This requirement is met by assigning different group codes to each station and arranging each station so that reception of a group code not associated with it locks out the supervisory equipment at that station. Initiation of a supervisory function by any station is prevented before completion of the first impulse of a received group-selection code, which is the first series of impulses transmitted for either a control or supervision function. Complete lockout is effected at the end of this series of impulses. After complete lockout, stations not involved in the function in progress can neither send nor respond to supervisory impulses until the reset signal is received. Any automatic operations of equipment that occur while a supervisory function is in progress are reported as soon as the channel is cleared by the reset signal.

There is a possibility that two or more controlled stations will start transmitting almost simultaneously to report automatic operations. In such a case it is necessary that the impulses from all such stations be synchronized with each other, so that the dispatching office and other stations will receive a coherent code. The actual code received by the dispatching office in such a case will be the longest code of those being sent, and those stations which send shorter codes will be locked out by the extra impulses. When the channel is cleared by the reset signal, they will again

start reporting by repeating their group-selection codes.

These requirements can be met by using external stepping and arranging the system so that every station receives its own signals as well as the signals of every other station. In this way synchronism of impulses is assured, because the impulsing of any station is governed by impulses which may be sent simultaneously from other stations.

In general, multistation supervisory control can be combined only with other noncontinuous carrierfunctions. Continuous functions, such as telemetering and load control, are excluded by the requirement that all stations receive all signals. Transmission of a continuous carrier from any station would prevent that station from receiving supervisory signals in a single-frequency system and might prevent other stations from receiving them in a two-frequency system.

When supervisory control is combined with communication on a multistation channel, the system must be arranged so that when one function is in progress it locks the other out. Communication must be locked out at all stations by the first supervisory impulse from any station. Lockout must continue until the supervisory operation is completed. Furthermore, the supervisory system at all stations must be locked out by communication from the moment the carrier is placed on the channel for ringing until the channel is released.

For single-station supervisory systems on point-to-point carrier channels, the requirements are somewhat less strict than for multistation systems, and the number of possible combinations is greater. Internal stepping can be used in single-station systems, and it is necessary only that a signal transmitted from one station be received at the other station. It is not essential that the transmitting station receive its own signals.

When supervisory control is operated over a carrier channel provided for its exclusive use, external impulsing with an unmodulated carrier signal normally is used. For this type of operation the transmitters and receivers at all locations operate on the same frequency, and all stations receive each other. Modifications of this arrangement must be made in some cases in order to combine the supervisory system with other functions.

Combination of Single-Station Supervisory Control With Other Functions on Point-to-Point Carrier Channels

1. Supervisory Control and Relaying. Carrier relaying normally is operated on an unmodulated carrier, with the carrier transmitter and receiver at each terminal set at the same frequency; thus all carrier signals from either station are received at both stations. It is possible to combine supervisory control with relaying on such a carrier channel without making any fundamental changes in either the carrier equipment or the relaying equipment. Since the channel issued for relaying only during fault conditions, it is normally free for use by the supervisory system. The relaying circuits must be arranged to take preference over any supervisory operation which may be in progress when a fault occurs.

This arrangement provides a simple method of combining relaying and supervisory control. However, the two functions are not entirely independent. The fact that both the relaying and the supervisory-control systems operate on straight carrier means that all relaying impulses are received by the supervisory equipment. If the supervisory system is at rest when the relaying equipment operates, it will be stepped off normal, making it necessary for the operator to reset it after each relaying operation. Likewise, if an automatic operation is being reported by the supervisory system when the relaying system operates, the supervisory signal will not be completed, and the operator must reset the equipment before the automatic operation can be reported. Starting of the carrier transmitter at either station for testing also must be followed by resetting of the supervisory equipment.

2. Supervisory Control and Communication. Supervisory control can be combined with communication of either the single-frequency push-to-talk or the two-frequency duplex type. The simplest way to make this combination is to make the communication function a point on the supervisory system. A contact in the telephone hook switch takes the place of the point-selection key which normally appears on the operator's supervisory-control board. Picking up of the telephone at either end sets the supervisory system into operation to select the corresponding telephone point at the other end of the channel. This rings the telephone bell at the other end. When the call is answered, circuits are set up through the hook switches to lock out the supervisory equipment until the telephones are restored. This system requires no audio-tone equipment but is suitable only for applications where telephone extensions are short, because of the number of separate circuits required in such extensions.

Standard two-frequency duplex carrier-communication assemblies use hybrid coils to combine receiver-output and transmitter-input circuits so that two-wire telephone extensions can be used. Supervisory control can be combined with such a system in such a way that the two systems are completely independent. This can be done by operating the supervisory system on an audio tone with tone-blocking filters to eliminate the supervisory tone frequency from the speech on the channel. A block diagram of this arrangement is shown in Figure 2.

3. Supervisory Control and Telemetering. The combination of supervisory control with continuous telemetering requires two carrier frequencies. The telemetering equipment is operated on an audio tone, modulating the carrier frequency, and at the station where the telemetering impulses orginate the supervisory system also must operate on an audio tone. At the other station, the supervisory equipment can operate on unmodulated carrier. This arrangement permits telemetering to continue during a supervisory operation. A number of different quantities can be telemetered continuously by using a different tone frequency for each.

The supervisory system itself can provide telemetering of one quantity at a time for short periods without the use of audio tones. In this case each telemetering function is made a point on the supervisory system and is selected by the operator in the same way a point is selected for a control function. After the operator has taken the required readings, he must reset the supervisory system so that automatic operations can be reported. This

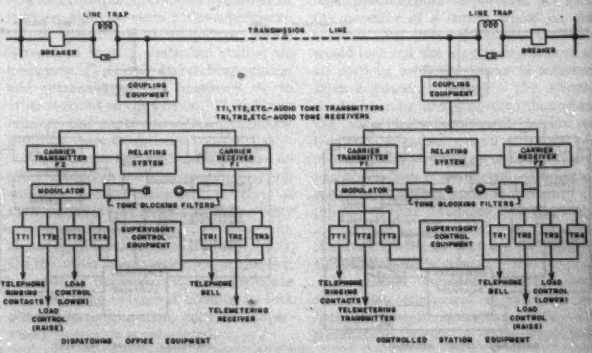

Figure 3. Combination of supervisory control with carrier relaying, communication, continuous telemetering, and load control

system, called selective telemetering, requires no audio tones in single-station supervisory systems and can operate on a single-frequency channel.

4. Supervisory Control and Load Control. The system described for continuous telemetering can be used for load control. The channel requirements are very similar, except that load control is necessarily a continuous function.

5. Supervisory Control, Relaying, and Communication. A limited form of carrier communication often is provided with carrier relaying equipment. Supervisory control best can be combined with these two functions by making the communication function a point on the supervisory system, as has been described for the combination of supervisory control with communication only. With some relaying systems a two-frequency duplex arrangement can be used, although the single-frequency system usually is used with carrier relaying.

6. Supervisory Control, Relaying, and Continuous Telemetering or Load Control. The requirements for this combination are the same as those described for the combination of supervisory control with continuous telemetering, that is, a separate carrier frequency must be used for transmission in each direction. This requires that the relaying system be capable of operating on such a channel.

7. Supervisory Control, Communication, and Continuous Telemetering or Load Control. Two carrier frequencies are required for this combination. The telephone ringing function can be performed either through the supervisory system or by using a separate tone frequency for the purpose. If the supervisory system is used for ringing, audio-tone transmitters are required for the supervisory system at the station at which telemetering and load-control impulses originate but not at the other station. Tone transmitters are required also for the telemetering or load-control function. If a separate audio tone is used for ringing, the supervisory system requires a separate tone transmitter and receiver at each station, regardless of the requirements imposed by the transmission of continuous telemetering and load-control impulses. In all cases, high-pass filters must be used to eliminate from the channel those voice frequencies which would interfere with the proper operation of the functions which use audio tones.

8. Supervisory Control, Relaying, Communication, and Continuous Telemetering or Load Control. The requirements for this combination are the same as those described for combination 7, with the additional requirement that the relaying system be capable of operating on a two-frequency channel. The relaying system, of course, must be arranged so that it can take control of the carrier from all other functions when a fault occurs.

This combination includes all the functions that have been considered. The block diagram of Figure 3 shows all the important components required to perform these functions with a single carrier transmitter and receiver at each terminal.

Combination of Multistation Supervisory Control With Other Functions

It has been pointed out that it is not possible to have continuous telemetering or load control in combination with multistation supervisory control on a single carrier channel. Certain considerations also make it inadvisable to consider the combination of multistation supervisory control with relaying on consecutive relaying channels. A separate carrier channel is required for each line section for carrier relaying, in order to prevent the possibility of false blocking of relaying signals. This means that any combination of supervisory control with relaying, in which the supervisory system extends beyond the line section protected by the relaying channel, requires the use of electronic or mechanical repeaters. The complexity of any such repeaters that would meet the requirements outlined for multistation supervisory control makes it preferable to use an entirely separate carrier channel for the supervisory-control system. It would be possible, however, to use a single set of coupling equipment for both the relaying and supervisory transmitters and receivers at each station.

1. Single-Frequency Communication Through a Point of the Supervisory System. Push-to-talk communication between the controlling or dispatching office and any controlled station on the supervisory system can be obtained by using a point on the supervisory system to provide selective ringing to each controlled station, and from controlled stations to the dispatching office. Since the supervisory-control system is intended only for selective functions between the dispatching office and controlled stations, and not between controlled stations, this system is limited to communication between the dispatching office and controlled stations only. Controlled stations cannot communicate with each other. This is no disadvantage, because the controlled stations of a supervisory system normally are unattended, and there would be no necessity for establishing communication other than that provided between the dispatching office and a controlled station.

In this system, the use of the supervisory equipment to perform the communication functions assures that the supervisory equipment is locked out at all stations until the conversation is completed.

The main components of this system are shown in the block diagram of Figure 4. A tone transmitter is used at the dispatching office for transmitting the reset signal. The usual method of resetting the supervisory system is the transmission of a long carrier impulse. This method cannot be used in a multistation system with communication because the placing of carrier in the channel for communication would be recognized by the supervisory equipment at all stations as a resetting impulse. The use of a tone to modulate the carrier for resetting provides a means of discrimination between a reset signal and carrier placed on the channel for communication. The tone-blocking filters are used to eliminate the resetting tone frequency from the speech before it is placed on the channel.

To call any one of the remote stations from the dispatching office, the operator picks up the telephone handset and operates the telephone selection key for the station to be called. The supervisory system transmits the group-selection code, which is returned by the remote station. The point-selection code is then transmitted from the dispatching office. Reception of this code at the called sta-

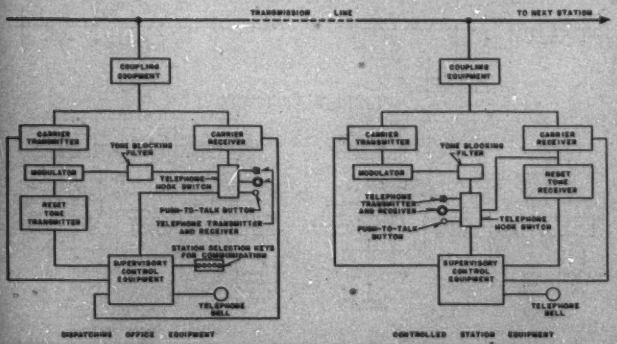

Figure 4. Multistation communication and supervisory control, with communication through a point on the supervisory-control system

tion rings the bell at that station. The point check code is not returned from the called station until the handset at that location is picked up. Reception of the point check code at the dispatching office indicates that the call is completed and establishes the push-to-talk communication circuits.

When the telephones are restored at the conclusion of the conversation, the resetting tone automatically is transmitted to reset the entire system to normal. Any automatic operations that have taken place at any point on the system during conversation then will be reported.

Communication is established in a similar manner from controlled stations. These stations communicate only with the dispatching office, and individual selection keys for calling are unnecessary. The telephone hook switch can be used to initiate operation of the supervisory system to call the dispatching office. Reception of the group- and point-selection codes at the dispatching office rings the telephone bell. When the operator picks up his handset, the point check code is transmitted, establishing the push-to-talk circuits at both stations. Resetting at the end of conversation is accomplished as before.

It is possible to obtain selective telemetering with this system without additional carrier equipment. The telemetering impulses are transmitted by unmodulated carrier, and resetting is accomplished by a modulated carrier impulse as before.

2. Two-Frequency Duplex Communication Through a Point of the Supervisory System. A two-frequency duplex form of communication can be obtained with a system very similar to that described under item 1. The equipment required is the same as that shown in Figure 4. The limitations given with regard to communication among controlled stations apply also to this system. In this case, the dispatching-office transmitter operates on a frequency F_1, which is received at all controlled stations. Internal stepping is used at the dispatching office. All controlled stations transmit on a second frequency F_2, which is received at the dispatching office. The requirment that all stations receive all signals is met by allowing the receiver at the dispatching office to key the dispatching-office transmitter; thus a signal sent from any controlled station is received at all stations, and external stepping can be used at the controlled stations. The procedure for establishing communication is the same as for the single-frequency system.

3. Semi-Independent Supervisory-Control and Two-Frequency Duplex Communication. The systems described under items 1 and 2 provide the combination of communication and supervisory control with a minimum of equipment. These systems are subject to the limitation that telephone extensions must consist of a number of conductors and be continuous metallic circuits. This limits the length of the extensions that can be used. It is occasionally desirable to use long two-wire telephone extensions, and such extensions may include insulating transformers which would interrupt d-c control paths.

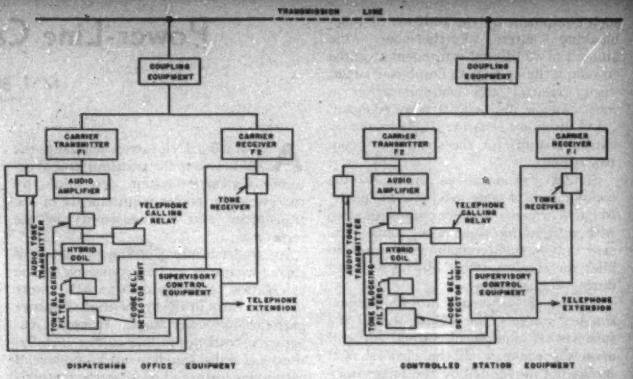

Figure 5. Semi-independent multistation supervisory-control and two-frequency duplex communication

The block diagram of Figure 5 shows the component parts necessary to combine supervisory control with a standard two-frequency duplex carrier communication assembly to provide semi-independent operation of the communication and supervisory systems. Two-wire telephone extensions are used. This system, like the others described, provides for communication between controlled stations and the dispatching station only, and not for communication among controlled stations.

The system is arranged so that the use of the carrier assembly for communication locks out the supervisory system at all stations, and vice versa. The supervisory system operates on an audio tone, which is received from a controlled station on frequency F_2 at the dispatching station and retransmitted on frequency F_1 to other stations on the system. Tone filters remove the supervisory-tone frequency from the voice frequencies transmitted.

When carrier is placed on the channel on either frequency for telephone ringing and subsequent communication, a relay at each location prevents the supervisory equipment from starting. Lockout continues until communication is completed. On the other hand, reception of the first supervisory impulse at all stations opens the telephone extension circuits to lock out all communication until the supervisory operation is completed.

The addition of selective telemetering to this system requires the use of a separate tone transmitter at the dispatching office and a separate tone receiver at each controlled station for resetting.

4. Multistation Single-Frequency Communication and Supervisory Control. In automatic simplex carrier-communication assemblies, the receiver is blocked during periods when the transmitter is in operation.[3] The fundamental requirement that external stepping be used in multistation supervisory-control systems makes it necessary to provide an additional carrier receiver at each station for the use of the supervisory equipment when this type of communication is combined with supervisory control. A tone transmitter and receiver are required for the operation of the supervisory system at each station in order to provide discrimination between carrier placed on the channel for communication and that placed on the channel for supervisory control. The use of tone equipment requires that tone-blocking filters be used in all speech circuits to prevent speech frequencies from impulsing the supervisory system.

With the equipment described, a combined system could be provided in which the presence of a carrier signal on the channel for communication purposes would lock out the supervisory system at all stations until the carrier is removed after a pause in speech. The system would have to be arranged so that when the supervisory equipment begins to transmit impulses, communication is locked out at all stations until the supervisory function is completed. The latter requirement would make it necessary to provide special means to lock out communication at all stations on the communication system that are not part of the supervisory system.

In general, automatic simplex communication equipment is intended for high-quality communication, and it is undesirable to modify the audio channels in

such equipment by the addition of tone-blocking filters. Furthermore, the amount of additional equipment required to adapt the system to combined supervisory control and communication in most cases would make it more economical to provide a separate single-frequency carrier channel for the supervisory-control system.

Similar considerations apply to the combination of semi-independent single-frequency manual simplex communication with multistation supervisory control, except that in such communication assemblies the receiver is not always disabled during transmission.

In both the automatic and the manual simplex systems, the locking out of the supervisory equipment would depend upon the presence on the channel of a carrier not modulated by the supervisory tone. At each pause in conversation this carrier would be removed, unlocking the supervisory control until transmission is resumed for communication. The possibility would exist that the supervisory system at one station would start transmitting at the same time that another station places carrier on the channel during communication. The latter station would not receive the supervisory impulses under these circumstances and might prevent proper reception of the impulses at one or more other stations. The supervisory equipment at some stations would not be locked out by the first group code under these conditions, a fundamental requirement for multistation operation.

Consideration has been given to means of locking out the supervisory equipment at all stations continuously during an entire communication period, irrespective of the presence of carrier on the channel. However, the amount of equipment involved in such schemes is considerable, and the arrangements are complicated.

These considerations lead to the general conclusion that, although multistation simplex communication and supervisory control can be combined in a single channel, it is advisable to use separate channels for these functions with joint use of coupling equipment only.

Conclusions

Single-station supervisory-control systems on point-to-point carrier channels can be combined in almost any desired combination with relaying, telemetering, load control, or communication. Internal stepping of the supervisory system can be used. Two-frequency carrier channels are required for the combination of supervisory control with continuous functions, such as telemetering or load control.

In multistation supervisory control systems, all stations must receive all signals, and external stepping of the supervisory system is required at all controlled stations. Continuous carrier functions cannot be combined with supervisory control on single-frequency carrier channels. Certain combinations of multistation supervisory control with relaying and communication equipment are not practical, for reasons that have been given. Methods of combining multistation supervisory control and certain types of communication in practical systems have been described.

Power-Line Carrier Channels

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A POWER-LINE carrier channel as the link between the transmitter and receiver of a carrier system, determines, by its losses, the power requirements of the transmitter and the sensitivity of the receiver.

An understanding of the operation of carrier channels and an approach to the calculation of losses to be expected were set forth early in the application of carrier currents to power lines. However, experience with power-line carrier installations has added much to our knowledge of actual line losses. Likewise, the methods used to apply carrier to the lines follow uniform practice, and the devices employed are reliable in performance. The losses introduced by their use are well understood.

As the art progresses, new applications are made, involving factors not previously of importance. Practical experience gained in these applications supplement the initial calculations, but the calculations must come first, and both theory and empirical data are of importance.

At the present time a stimulus has been given power-line carrier activities by the introduction of audio-frequency tones for extended use of a single-channel frequency modulation as a means of limiting effects of interference, and single-sideband transmission as a method of increasing the number of useful channels. Channels will be established on lower-voltage lines to an increasing extent.[1,2,3]

In the interest of a better understanding of the factors which must be considered in the extension of power-line carrier applications, the following discussion of theoretical and practical experience is offered.

High-Frequency Transmission-System Losses

The transmission lines of a power system become high-frequency transmission lines when power-line carrier is applied to them. Factors which are not a consideration at power frequencies become important to a degree that they must be taken into consideration at carrier frequencies if an entirely workable system is to be designed.

Transmission losses are proportioning functions. That is, the received signal strength is only a fraction of the transmitted signal strength, and that fraction is numerically equal to the product of fractions expressing the transmission characteristics of the various components in the circuit. If the logarithm of these fractions, based on the ratio of power in to power out, is used instead of the actual ratio itself, these logarithms may be added to obtain a logarithm representing total loss. This is a convenience, because the addition of these figures is simpler than the multiplication of loss ratios. The decibel is the unit used in these calculations and is numerically expressed as follows:

$$\text{db} = 10 \log_{10} \frac{P_1}{P_2}$$

where

db = decibels loss (attenuation)
P_1 = power into a device
P_2 = power out of a device

If the loss encountered in each series device of a transmission system is expressed in decibels, then the total loss in decibels is the sum of the losses in decibels. Therefore, if it is known that a transmitter–receiver combination works successfully through an attenuation of a specific number of decibels, the system will be workable if the total losses encountered are less than this value. As the transmitter power is increased, the number of decibels that it will work

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References

1. A Versatile Power-Line Carrier System. H. W. Lensner, J. B. Singel. AIEE Transactions, volume 63, 1944, March section, pages 129–32.

2. Possibilities and Methods of Extending a Carrier-Current Relaying Channel to Other Uses. R. M. Smith, S. L. Goldsborough. AIEE Transactions, volume 60, 1941, January section, pages 23–7.

3. Electronic Switching Simplifies Power-Line Communication. J. D. Booth. *Electronics*, volume 15, May 1942, pages 44–7.

through, with a given receiver, increases. Likewise, as receiver sensitivity is increased, the attenuation through which it will operate successfully with a given transmitter increases.

Obviously there are economical limits of transmitter size and limits on interference-free receiver sensitivity. Thus transmitter–receiver combinations in practical use are not numerous. The lower-powered combinations are designed to operate through losses up to 30 decibels, and the more elaborate equipment is rated correspondingly higher.

High-Frequency Transmission Lines

A transmission line for high frequency can be considered ideally as an infinitely long pair of equally spaced wires of the same diameter throughout, supported in free space without inductive or capacitive coupling to other circuits. Lines of this type have been treated mathematically on the basis that they are composed (Figure 4) of an infinite number of resistors and inductors in series and having an infinite number of capacitors and resistors shunting the lines at equally spaced points along the lines.[4]

Several important concepts are derived from this treatment. One is that an infinitely long transmission line, because it cannot reflect energy back toward the transmitting end, displays a characteristic impedance that is a function of the resistance, inductance, leakage, and capacitance of a unit length. Quantitatively this impedance is as follows:

$$Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}}$$

where

R = ohms resistance per unit length
L = henrys inductance per unit length
G = mhos conductance of leakage per unit length
C = farads capacity per unit length
$\omega = 2\pi f$ where f is frequency in cycles

Now if the transmission-line conductors are severed at a finite distance from the sending end, the impedance displayed by the remaining infinite section is still the characteristic impedance of the line. It follows then that if we terminate a finite length of transmission line with an impedance equal to the characteristic impedance of the line, then no reflections will be received at the sending end, since this was the case when the finite section was terminated with the infinite line. This is another important concept employed in power-line carrier systems. The impedance of the receiving system must be equal to the characteristic impedance of the line if the sending end is to be free of received reflections.

It is an interesting commentary at this point to note that the transmitter internal impedance, as viewed from the line through the transmitter output transformer is also related, in best practice, to the characteristic impedance of the line although for a different reason. The transmitter operates most efficiently from the standpoint of high carrier output and low harmonic output when its internal impedance and its load impedance are properly proportioned. A ratio of load impedance to tube impedance of 2 to 1 was shown by Hanna,[5] Sutherland, and Upp, as being most efficient for triodes, whereas Pidgeon shows that ratios of 1 to 3 to 1 to 10 are common practice for pentodes.[5,6]

Since the R and G terms in the formulas for characteristic impedance are negligible in open-construction power lines, because the resistance and leakage are low compared to the reactance components, the

Figure 1 (left). Terminal equipment for two single-line-to-ground power-line carrier channels on a 69-kv line

Figure 3 (right). A single-phase suspension-mounting by-pass unit for bridging an autotransformer in a line

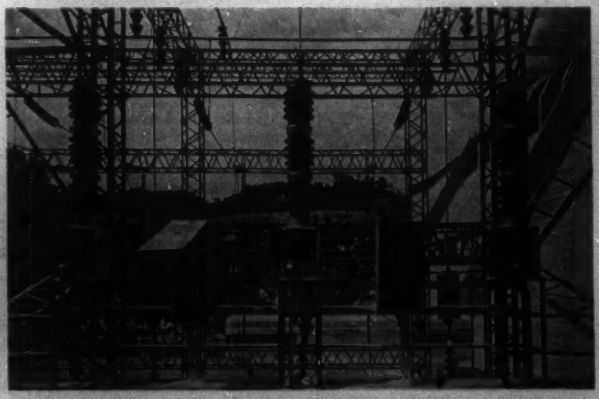

Figure 2. Terminal equipment on a 154-kv line

The two outer phases are used for communication operating line to line, and the inner phase is part of a line-to-ground relaying channel

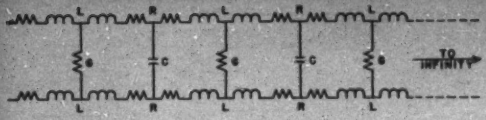

Figure 4. The equivalent diagram of the infinite line

formula for characteristic impedance simplified into

$$Z_0 = \sqrt{\frac{L}{C}} = 276 \log_{10} \frac{2D}{d}$$

where D is the distance between conductors, and d is the diameter of the conductor.[7]

Ordinary high-voltage transmission lines display characteristic impedances of 800 to 850 ohms for line-to-line channels and about 500 ohms for line-to-ground channels. Power cable will display an impedance in the order of 25 ohms. Even lower impedances are encountered in some special carrier installations, such as train communication, where track to ground leakage is high, and impedances in the order of 3.5 to 7 ohms are experienced.[8]

It long has been standard practice to isolate spur lines by series line traps to prevent attenuation due to reflections received from the end of the spur line.

Therefore, an attempt is made to terminate each carrier channel in the characteristic impedance of the line, and on spur lines where it is not possible to do so the line is isolated.

While this may appear to be an ideal treatment, it is approached in practice on relaying channels which extend from only one end of a transmission-line section to another. Channels used for communication, telemetering, and supervisory control, however, may be carried through a considerable network and have many terminals. Such systems often cannot be made free of reflections, but all frequencies of transmission are not affected alike, and a selection can be made of a frequency least affected by reflection losses. System switching operations which alter the carrier channels also must be considered in the study of system arrangement when the optimum frequency is being selected. Further, undesired paths through parallel lines and into spur lines should be eliminated by putting line traps in series with such lines.

The Attenuation of Carrier Frequencies in Transmission Lines

A further study of the infinite transmission line reveals that carrier current which is applied at the transmitting end of the line changes in both phase and magnitude as it progresses along the line.

The change in magnitude is expressed:

$$I_2 = I_1 \epsilon^{-\alpha X}$$

where I_1 is the sending-end current, I_2 is the current at a point X distance in miles from the sending end, and α is the attenuation constant.

The phase position is shifted backwards as the distance from the sending end increases. The position is given by the equation:

$$I_2 = I_1 \epsilon^{-j\beta X}$$

where β is the wave-length constant. It is the number of radians per mile which the current vector is shifted backwards. These may be combined to give the complete expression:

$$I_2 = I_1 \epsilon^{-X(\alpha + j\beta)} = I_1 \epsilon^{-PX}$$

and, since the characteristic impedance is a pure resistance, the voltages may be expressed as

$$E_2 = E_1 \epsilon^{-X(\alpha + j\beta)} = E_1 \epsilon^{-PX}$$

where E_1 is the sending-end voltage, E_2 is the voltage at a point X miles from the sending end, and P is the propagation constant which is equal to $(\alpha + j\beta)$. Figure 5 is a graphical representation of conditions along a transmission line carrying a high-frequency current.

Of particular interest in estimating the expected losses due to line attenuation is the attenuation constant, α. Its more complete form is simplified for the transmission-line case when leakage is considered negligible compared to resistance and both leakage and resistance are considered negligible compared to reactance. It then becomes:

$$\alpha = \frac{R}{2Z_0} = \frac{R}{2}\sqrt{\frac{C}{L}}$$

The resistance R is the resistance of the transmission-line conductor at carrier frequencies. Its determination is difficult because of many factors which must be considered in skin-effect calculations. The case of solid and tubular conductors has been well studied, and reliable formulas have been developed for determining radio-frequency resistance.[9] B. R. Teare and Josephine R. Webb have shown that copper-clad steel conductors have a resistance substantially equal to the tubular copper portion alone for frequencies up to 160 kilocycles.[10] However, stranded transmission-line conductors introduce many factors, such as number and size of strands, that all have an effect on high-frequency resistance. Unfortunately, the solid conductors about which the skin-effect literature has been most concerned is the exception rather than the rule in transmission-line construction, and thus the formulas offered do not apply in many cases. Experience with concentric stranded cable has shown that new cable with bright conductors shows a definitely lower high-frequency resistance than that with weathered conductors. It has been suggested that in the first case the current travels from conductor to conductor in a direction parallel to the axis of the conductor and in the latter case must spiral around the axis of the cable, following the convolutions of the outer conductors, since corrosion prevents passage from one conductor to another.

Literature dealing with power-line carrier attenuation has repeatedly indicated that attenuation experienced on lines has been in excess of the calculated attenuation. Boddie and Curtis stated that measurements on a number of lines indicated that the actual line resistance was about 250 per cent of the calculated value. Their calculations assumed that stranded conductors were equivalent to solid conductors of the same copper cross section. Likewise, Laughlin, Pakala, and Reagan reported losses on the Boulder Dam lines of five times calculated losses.[11] The latter reference used the formula for tubular conductors in determining the high-frequency resistance of the line conductors. Actually the Boulder Dam conductors are tubes made of flat interlocking segments spiraled along the axis of the conductor. Some variation from the tubular-conductor formula results should be expected in this case; however, it seems doubtful that the entire discrepancy between calculated loss and actual loss was due to an error in the determination of conductor resistance. The authors point to the possibility of losses in

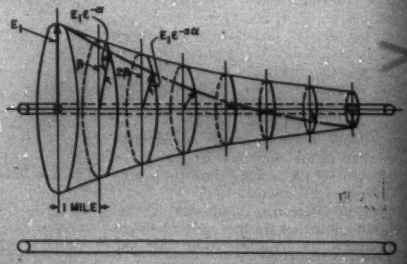

Figure 5. Diagram showing the phase and magnitude of potential at various points along a line

other phase conductors and the ground circuits being responsible.

While an exact evaluation of attenuation by calculation has not proved to be entirely successful, empirical data have been accumulated that allow the engineer to estimate the attenuation to be expected on ordinary lines. One simple formula that can be applied with reasonable accuracy for attenuation of power-line carrier in the 50- to 150-kilocycle range on lines of 34.5 kv and above is as follows:

$$\text{db per mile} = k[0.01 + (kc \times 10^{-3})]$$

where kc is the frequency in kilocycles and k is a multiplying factor of 1.6 for line-to-ground coupling and 1.3 for line-to-line coupling. This expression will predict higher losses than will be encountered in most instances and thus afford a factor of safety in its use. Rives offers curves for attenuation in the range from 30 to 200 kilocycles.[12]

Although it was pointed out that the best practice dictates terminating a line in its characteristic impedance to prevent reflections, the complex nature of the receiver circuit impedances makes it difficult to be assured that a line is so terminated. Consequently, attenuation curves run on actual installations will not show a smooth variation in attenuation with frequency.

Coupling Losses

The carrier energy in flowing from the transmitter terminals to the power line encounters losses in the coaxial cable, coupling capacitor, and line-tuning units, and upon arrival on the line is offered a shunt path through the line trap to a return circuit of widely varying characteristics. It is, therefore, of interest to determine losses in the coupling equipment, since these losses at both the transmitting and receiving end must be added to the line losses.

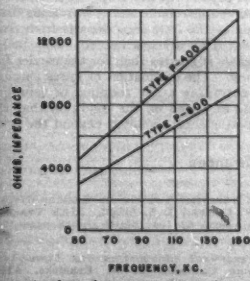

Figure 6. Impedance at resonance for typical single-frequency line traps

Double-frequency tuning reduces the peak impedance about 50 per cent. Values taken from this curve are used directly with either the single- or double-frequency impedance curves of Figure 7. Type P-400 is 400-ampere size, and type P-800 is 800-ampere size

The line-tuning unit and coupling capacitor are adjusted on installation to be resonant with each other at the operating frequency. Therefore, the losses in the line-tuning unit are related to the capacitance value of the coupling capacitor, because this value determines how much inductance is required. If constant Q for the line-tuning unit is assumed, the coil losses are proportional to its inductance. In the range from 15 to 345 kv, the capacitive reactance of standard coupling capacitors varies from 320 to 4,250 ohms at 50 kilocycles, and correspondingly less at the higher frequencies. Table I shows the approximate total resistive component of standard-size coupling capacitors and their resonating inductances. The values of capacitor power factor and coil Q generally will differ in actual practice for a specific application from those used in the table. Therefore, the table should be used only for estimating purposes.

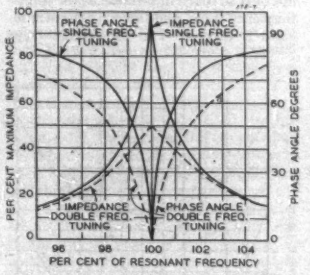

Figure 7. Resonance curves for typical line traps

The losses of the coil and capacitor add in this circuit to give a resistive component of about six per cent of the capacitive reactance; consequently, the equivalent series resistance for these two devices is between 20 ohms at 50 kilocycles for a 15-kv capacitor and 320 ohms at 50 kilocycles for a 345-kv capacitor.

Obviously, the losses will be negligible if the ratio of this resistive component to the characteristic impedance of the line is small, as it is in most cases. If the ratio does not exceed 1 to 5, the loss will be one decibel or less. However, coupling into a cable which has a low characteristic impedance, through a high-voltage capacitor, will introduce losses that must be taken into account.

For example, in the case of a 69-kv coupling capacitor operating through a line tuner into a cable of 25 ohms characteristic impedance, the resistive component of the coupling capacitor and tuner will be 70 ohms, and the losses will be six decibels.

Table I. Approximate Equivalent Resistance of Resonated Coupling-Capacitor Circuits

Line Couplers or By-Pass Equipment
Capacitor Power Factor = 4 Per Cent

$$\text{Coil } Q = \frac{\omega L}{R} = 50$$

$$R = X_C(\text{Power Factor} + 1/Q)$$

System Voltage, Kv	Coupling-Capacitor Value, μf	Reactance at 50 Kc	Approximate Equivalent Resistance R, Ohms at 50 Kc
15	0.01	320	20
23	0.0075	430	25
34.5	0.005	640	38
46	0.004	800	48
69	0.00275	1,160	70
92	0.002	1,600	96
115	0.00187	1,700	104
138	0.00137	2,320	139
161	0.00125	2,550	153
196	0.00094	3,390	203
230	0.00094	3,390	203
287.5	0.00075	4,250	255
345	0.0006	5,300	320

By-Pass Equipment

A by-pass unit is simply one or more coupling capacitors with their associated line-tuning units.

If an autotransformer in a line must be by-passed, only one capacitor and line-tuning unit are required; however, if a breaker is to be by-passed, a coupling capacitor and line-tuning unit on each side of the breaker are required with drain coils to ground at the interconnection between the line-tuning units. The drain coil avoids power-frequency charging current being put on a de-energized line.

The losses will be the same as for an equivalent number of coupling capacitors and line-tuning units, and like coupling capacitors will be of added importance on lines of low characteristic impedance.

Coaxial Transmission Lines

Coaxial cable is used in many installations as the means of carrying transmitter power through the switchyard to the line-tuning equipment and coupling capacitor. Likewise, it serves as a channel for the received signal coming into the receiver and as an interconnection between units of a by-pass arrangement.

Such runs occasionally are in excess of 1,000 feet but usually only a fraction of this. The cable losses increase with frequency. At 150 kilocycles the loss is 0.5 decibel per 1,000 feet in the type of cable in ordinary use.

The transformer equipment that is supplied by the manufacturers of power-line carrier equipment for matching into these cables is highly efficient and fully adjustable, so that the input to the cable

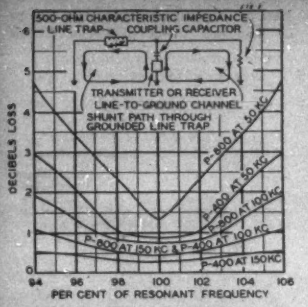

Figure 8. Losses in 400-ampere (type-P-400) and 800-ampere (type-P-800 single-frequency line traps when a line-to-ground carrier channel of 500 ohms characteristic impedance is short-circuited through line trap

and output from it can be matched properly to the cable characteristic impedance, and no loss is encountered from mismatch conditions.

Power-Line Carrier-Line Traps

The attenuation due to line traps varies with the type of trap, the method of tuning (single or double frequency), the relation between the frequency being transmitted and the resonant frequency of the trap, and the conditions of the line beyond the trap.

The high-frequency current, after leaving the transmitter and the line-tuning unit, passes through the coupling capacitor to the transmission line as shown in Figure 8. The current is divided into two parts, one part continuing down the line toward the distant terminal and the other part passing through the line trap. In Figure 8 it is assumed that the line beyond the trap has zero impedance. Actually, the line beyond the trap can be any impedance from zero to nearly infinity and can be either resistive, capacitively reactive, or inductively reactive. The total reactance of the shunt path is the vector sum of the line-trap impedance and return-path impedance.

The line trap being a parallel resonant circuit displays an impedance which is a complex quantity whose components vary with frequency. The peak impedance at resonance increases with frequency as shown in Figure 6. On either side of resonance the impedance drops off as shown in Figure 7. The phase angle of the impedance also is shown on Figure 7. The impedance of the trap is inductively reactive below resonance and capacitively reactive above.

Consequently the sum of the line-trap impedance and the return-path impedance conceivably can be any combination of reactance and resistance within the limits of these two elements. It can be conceived that the reactive component of the line trap can resonate with an equal reactive component of opposite sign displayed by the return circuit, thereby cancelling out the reactive components and leaving only the resistive components. If the line showed low resistance, this condition would produce a shunt path of low impedance with high attenuation. While theoretically possible, it is unlikely that this condition will be experienced in practice. However, the condition where the return path is of zero impedance can be approached and for practical purposes may be considered as the extreme condition.

The attenuation of the carrier signal by the shunt path through the line trap is shown in Figures 8 and 9. It will be seen that, as the carrier frequency departs from the resonant frequency of the trap, it suffers more attenuation. Likewise, the double-frequency line traps do not offer so much impedance as the single-frequency traps, and therefore the attenuation is higher. The 400-ampere traps

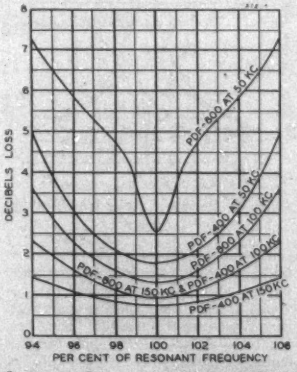
PDF-800 AT 50 KC
PDF-400 AT 50 KC
PDF-800 AT 100 KC
PDF-800 AT 150 KC & PDF-400 AT 150 KC
PDF-400 AT 150 KC
DECIBELS LOSS
PER CENT OF RESONANT FREQUENCY

Figure 9. Losses in 400-ampere (type-PDF-400) and 800-ampere (type PDF-800) double-frequency line traps when a line-to-ground carrier channel of 500 ohms characteristic impedance is short-circuited through line trap

because of their higher impedance show less attenuation than the 800-ampere traps.

These curves are based on the assumption that the transmitter is a constant-current generator, operating into a load impedance consisting of the line trap in parallel with the 500-ohm characteristic impedance of the line. The power into the 500-ohm branch decreases as the impedance of the line trap decreases. The constant-current characteristic is approached closely by a transmitter whose internal impedance is high compared to the load impedance, as is the case with transmitters having pentodes in the output stage.

Examination of the circuit of Figure 8 will show that, if a receiver is considered instead of a transmitter, the results will be the same, and the curves are valid for the receiving end as well as the transmitting end. In this case, the line is the current source, and the receiver can be assumed to be a 500-ohm load paralleled by the line trap.

It should be noted that these curves are not for normal operating conditions but for a condition which for practical purposes may be considered as producing the most attenuation. This condition is of importance in carrier relaying, because the channel over which a blocking signal must be transmitted is paralleled by a path through the line trap and an external fault.

Conclusions

1. Although the phenomena of high-frequency transmission are understood, there is still a lack of quantitative information on the high-frequency resistance of transmission-line conductors and ground paths and the losses in the impedance introduced into a channel by coupling with other phase conductors. Power-line carrier-channel losses therefore are more reliably computed from formulas and curves based on empirical data, than from the basic formulas.

2. Coupling capacitors, line-tuning units, and by-pass units normally are of such high efficiency in their operation that their losses may be neglected or appraised at some nominal low value in the order of one or two decibels. However, in special cases such as the operation into lines or cables of low characteristic impedance, consideration of losses in the coupling capacitor, line-tuning units, and by-pass units is required.

3. Line traps ordinarily function with very little loss, but if the channel is short-circuited beyond the line trap, the attenuation becomes appreciable and of increasing magnitude as the frequency departs from resonance. The attenuation for side bands therefore is greater than for the carrier frequency. The calculation of losses through a line trap at a line terminal or spur line should be based on the condition that the channel is short-circuited beyond the trap.

References

1. A Versatile Power-Line Carrier System. H. W. Lenner, J. B. Singel. AIEE Transactions, volume 63, 1944, March section, pages 129-33.

2. Frequency Modulation for Power-Line Carrier Current, E. W. Konefake. AIEE Transactions, volume 62, 1943, October section, pages 616-19.

3. A Comparison of the Amplitude-Modulation, Frequency-Modulation, and Single Side-Band Systems, R. C. Cheek. AIEE Transactions, volume 64, 1945, May section, pages 218-20.

4. Communication Engineering (book), W. L. Everitt. McGraw-Hill Book Company, Inc., New York, N. Y.

5. Development of a New Power Amplifier Tube, C. R. Hanna, L. Sutherlin, C. B. Upp.

Effect of Altitude on Temperature Rise of Aircraft Transformers

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THE PURPOSE of this paper is to present a method of calculating the effect of altitude on the temperature rise of various designs of aircraft transformers which are required to operate at extremely high altitudes.

So far as is known the tests reported in Mr. Kiltie's[1] paper are the first ones that have been made under conditions representing such a wide range in altitude—up to 40,000 feet—on an actual transformer. The fact that there is very close agreement between the calculated values and observed values lends confidence in our ability to calculate the effect of altitude on the temperature rise of other types of electric apparatus, provided, as pointed out later, that the percentages of the loss of heat by convection and by radiation at sea level are known.

The effect of altitude on temperature rise of a simple piece of apparatus like a self-cooled transformer can vary as much as 2.5:1, depending on the per cent of the loss of heat by radiation (dependent on outside envelope of the cooling surface) and the loss by convection (dependent on the total developed area of cooling surfaces), because only the loss by convection is affected by altitude. It is for this reason that no two types of apparatus will be affected alike by altitude.

The effect of altitude on transformers is of course least for one with a plain tank for which at sea level approximately 45 per cent of the total loss is dissipated by convection and 55 per cent by radiation, and greatest where all loss of heat is by convection as from the inside of ventilated windings of dry-type natural-draft transformers.

As the aircraft transformer used for Mr. Kiltie's tests had no ventilating ducts in the winding and whereas most, if not all, of the losses were dissipated to the air from the outside surface, it should follow quite closely the behavior of a plain-tank surface. This is particularly true of the outer coil, since the temperature rises reported were those of the outside surface.

Figure 1 shows temperature rise versus loss of heat by convection and by radiation as calculated[2] by equations shown with Figure 1. The barometric pressures used for ρ were based on equation 11 of reference 2.

As a basis for selecting the tested temperature rises of the coils, it is believed that the average of the rises obtained with and without the Durel mounting plate should be used to compare with the calculated rises. There is not very much difference—the calculated rise being slightly higher than the tested when the mounting plate was used and slightly lower when the plate was not used.

Table I shows a comparison of the tested and calculated rises for the outer coil. The calculated values were obtained by finding the total losses W_c and W_r from Figure 1 that correspond to the sea level temperature rise, and then finding by trial the temperature rise at the higher altitudes that gave the same total losses, the copper loss being corrected for the higher rise at the higher altitude. For example: for 150 degrees-centigrade rise at sea level, Figure 1 gives a total loss of W_c and $W_r = 1.91$ watts per square inch. For 25,000 feet the loss is $1.91 \times 1.055 = 2.02$. A temperature rise of 173 degrees gives, by Figure 1, a total watts per square inch of 2.01.

There is some uncertainty as to how to calculate the temperature rise of the inner coil, since the internal temperature drop should not be affected by air density to the same extent as the outside surface rise over air is affected. Unless low air pressure affected the internal temperature drop, the increase in temperature rise of the inner coil should be approximately the same number of degrees as found for the outer coil, since most of its loss was probably dissipated to the air from the outside surface of outer coil, some from the edges of the inner coil, and perhaps some by the core.

In Table II are the tested and calculated temperature rises of the inner coil based on the assumption that its rise was increased by altitude the same number of degrees as the outer coil was increased.

Table II indicates that the internal

Table I

Altitude, Feet	Surface Temperature Rise of Outer Coil, Degrees Centigrade: Test*	Calculated	Ratio of Copper Loss
Sea level	150	150 (base)	1.0
12,000	161.5	161.5	1.03
25,000	172.5	173.0	1.055
40,000	189.5	185.0	1.10

*Average of coil rises with and without Durel mounting plate.

Table II

Altitude, Feet	Temperature Rise of Inner Coil, Degrees Centigrade: Test*	Sea-Level Test**	Calculated
Sea level	196.5	196.5 + 0	= 196.5
12,000	209.5	196.5 + 11.5	= 208.0
25,000	225	196.5 + 23	= 219.5
40,000	239	196.5 + 35	= 231.5

*Average of rises with and without Durel mounting plate.

**Calculated temperature rise of outer coil over rise at sea level.

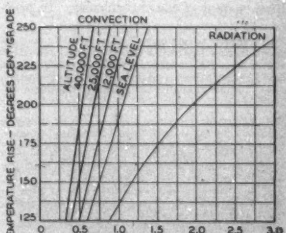

Figure 1. Loss by convection and by radiation

$W_c = 1.4 \times 10^{-3} \times \theta^{1.25} \rho^{0.5}$

ρ = relative air density to sea-level density

$W_r = 3.68 \times 10^{-11} e (T_2^4 - T_1^4)$

e = 0.95 (emissivity factor)

$T_2 = 273 + 30 + \theta$

$T_1 = 273 + 30$-degrees-centigrade ambient temperature

Altitude, feet:	Sea level	12,000	25,000	40,000
Relative air density:	1.0	0.662	0.425	0.254

Paper 45-75, recommended by the AIEE committee on air transportation for presentation at the AIEE winter technical meeting, New York, N. Y., January 22-26, 1945. Manuscript submitted November 27, 1944; made available for printing January 2, 1945.

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Proceedings of the Institute of Radio Engineers, 1928.

6. THEORY OF MULTIELECTRODE VACUUM TUBES, H. A. Pidgeon. AIEE TRANSACTIONS, volume 53, 1934, pages 1485-98.

7. C. A. Boddie. Institute of Radio Engineers *Transactions*, June 1927.

8. TRAIN COMMUNICATION, L. O. Grondahl, P. W. Bossart. AIEE TRANSACTIONS, volume 62, 1943, July section, pages 493-500.

9. Bureau of Standards circular 74.

10. SKIN EFFECT IN BIMETALLIC CONDUCTORS, B. R. Teare, Jr., Josephine R. Webb. AIEE TRANSACTIONS, volume 62, 1943, June section, pages 297-302.

11. CARRIER-CURRENT LOSSES MEASURED AND INTERFERENCE MINIMIZED ON BOULDER-LOS ANGELES TRANSMISSION LINE, J. D. Laughlin, W. E. Pakala, M. E. Reagan. AIEE TRANSACTIONS, volume 59, 1940, January section, pages 4-10.

12. APPLICATION OF CARRIER TO POWER LINES, F. M. Rives. AIEE TRANSACTIONS, volume 62, 1943, pages 835-44.

Rectifier Relay for Transformer Protection

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THE BASIC PRINCIPLE of differential protection of electric equipment consists of measuring the sum of the currents at the various terminals of the generator, transformer, or bus. If the vector sum of these currents is substantially zero, there is no fault; if the vector sum is not zero, a fault condition is indicated.

In the case of transformer protection, the effect of the exciting current plays an important role, inasmuch as exciting current is equivalent to fault current from the standpoint of differential protection. Under normal conditions of operation, when the exciting current is less than ten per cent of full-load current, the exciting current easily can be provided for in the setting of the relay. However, because of the high value of exciting current which may flow at the instant a transformer is energized, unnecessary operations of the differential relay may occur when a transformer is being energized.

The excessive exciting current which may occur at the instant of energizing a transformer, commonly known as the inrush current, is due to the combined effects of transformer saturation, residual magnetism, and the transient d-c component in the current wave.[1] Inrush currents are a random phenomenon and can vary in magnitude from practically normal exciting current to several times full-load current of the transformer. In practice, heavy inrush currents can be expected in a large percentage of energizing operations, since the conditions required for low inrush currents are rather limited. An example of a heavy inrush current is shown in Figure 1. In this case, the first peak has a value equal to approximately three times the full-load current of the transformer.

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P. N. Sandstrom, deceased, was responsible for the development of the relay described in this paper. The author acknowledges the assistance of R. I. Ward in the development of the relay and preparation of the paper.

Methods to Prevent Relay Operations Resulting from Inrush Currents

The need to prevent operation of transformer differential relays due to inrush current has been accentuated greatly by the use of sensitive high-speed relays. With slow-speed and insensitive relays, the rapid decrement of the exciting current eliminates unnecessary relay operations. With sensitive high-speed relays, which trip in one to three cycles, a special method must be provided to prevent operations due to inrush current. Some of the methods which have been used for this purpose consist briefly of the following arrangements:

1. One method makes use of the fact that inrush current contains a high percentage of harmonic currents and a large d-c component. The direct and harmonic currents are separated by means of filters from the fundamental current and are used to restrain relay action. On actual faults, the harmonic currents will be small compared to the total fault current and sensitive action is obtained.[2]

2. In another method, voltage relays are used to block the tripping action of the differential relay, if there is no appreciable reduction in bus voltage at the instant of energizing the transformer. This blocking action exists only long enough to permit the inrush current to decline to normal value. If a fault exists in the transformer circuit at the time it is energized, the bus voltage decreases and the tripping action of the differential relay is not blocked.

3. In a third method, the operating coil of the differential relay is desensitized for a short time after the transformer is energized. This is accomplished by partially short-circuiting the operating coil of the relay by the manual switch used for closing the transformer breaker.[3] It has been found that on induction-type percentage differential relays with a minimum operating current of two amperes, a desensitized setting of four to five amperes gives satisfactory results.

Principle of the Rectifier Relay

This paper describes a new principle which has been applied for the purpose of eliminating incorrect relay operations resulting from inrush currents. The method used does not decrease the sensitivity of the relay at the instant the transformer is energized. This principle of the new relay is based on the fact that the inrush current is a pulsating direct current of positive or negative polarity. Figure 2 shows the method used for taking advantage of this situation. Two relays are used in series with dry-type rectifiers, so that one relay functions on positive current and the other on negative current. In order to close the tripping circuit, both relays must be energized. In the case of an inrush current, only one relay will be energized and no tripping will result. In the event of a fault with substantially equal positive and negative currents, both relays will trip and the transformer will be cleared from the system.

While the foregoing describes the principle of the rectifier relay from the theoretical point of view, a very important practical situation must be taken into account. As shown on Figure 1, the inrush current is by no means a direct current with respect to the secondary circuit, although the primary current is substantially direct. Within approximately five cycles after the transformer of Figure 1 is energized, an appreciable a-c component of current appears in the secondary circuit. This alternating current is a result of current-transformer saturation caused by the flow of direct current through the current transformer, a phenomenon which has been discussed and analyzed in recent AIEE papers.[3,4] The magnitude of the a-c component and the time required for it to appear in the circuit will vary principally with the construction of the current transformer and the resistance of the secondary circuit.

In order to prevent tripping due to the false a-c component, a time-delay auxiliary relay was added which functions in the following manner. As shown in Figure 3, if either of the two primary relays trip, the auxiliary relay A is energized. After 1.5 cycles, the relay trips, contact A is closed, and a resistor R is connected across the current circuit of the primary relays. The effect of this resistor is to desensitize the primary relays, thus re-

temperature drop through the insulation and air interstices was increased slightly by low air densities as would be expected.

The important point to remember is that these tests gave the minimum effect of altitude on the temperature rise of air-cooled transformers, because the losses were dissipated from a plain surface in which the loss of heat by radiation (unaffected by altitude) in percentage of total loss was the maximum possible.

Calculations indicate that, if the copper loss of this transformer had been dissipated entirely by convection air currents, the temperature rise at 40,000 feet probably would have been (when taking into account the increased copper loss due to temperature rise) in the order of 350 degrees centigrade instead of 189.5 degrees centigrade.

References

1. AIRCRAFT TRANSFORMERS—SMALL AND LIGHT, O. Kilbe. AIEE TRANSACTIONS, volume 62, 1943, pages 897–902.

2. EFFECT OF BAROMETRIC PRESSURE ON TEMPERATURE RISE OF SELF-COOLED STATIONARY INDUCTION APPARATUS, V. M. Montsinger. AIEE TRANSACTIONS, volume 35, 1916, pages 599–636.

Figure 1. Typical example of transformer inrush current. First peak of lower wave is approximately three times full load current of transformer

quiring a heavier current to trip. When the inrush current subsides to a value below the tripping value for the primary relay, the auxiliary relay drops out and the sensitive setting is re-established. In an application discussed later, it was found that a sensitive setting of 2.5 amperes and a desensitized setting of 5.0 amperes gave satisfactory operation.

If a fault occurs with a symmetrical current wave, the two primary relays will trip in approximately one cycle and the auxiliary relay plays no part in the operation. If a fault occurs with a displaced current wave, the action will depend upon the degree of asymmetry, the magnitude of the fault current, and the d-c decrement. In many cases, the fault current will be sufficiently high and the d-c decrement sufficiently fast so that the speed of tripping will not be affected by the desensitizing action. For faults with displaced waves of low magnitude and a relatively slow decrement of the d-c component, the desensitizer will take effect and a fault current higher than the desensitized setting will be required for tripping. For the applications being considered, this latter condition did not appear to be very important, since even the desensitized setting of the relay was lower than the setting of comparable relays.

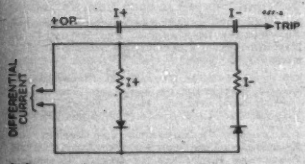

Figure 2. Basic connections of rectifier relay

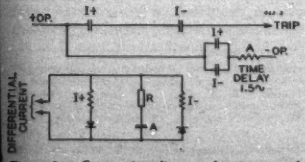

Figure 3. Connection diagram showing use of time-delay relay for desensitizing primary relay

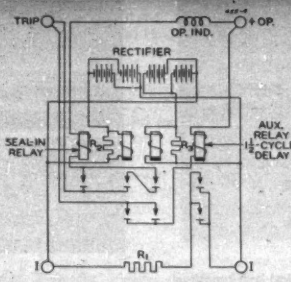

Figure 4. Connections of completed relay

One limitation arises in regard to the dropout value for the primary relays. It is necessary for the dropout current with the desensitized setting to be lower than the pickup value with the sensitive setting. If this condition is not obtained, it is possible for the breaker to be tripped at the instant when the primary relay drops out and sensitizes the relay. In the application described later, the pickup for the sensitive condition was 2.5 amperes and the dropout for the desensitized condition 2.3 amperes.

Application of Rectifier Relay

A number of laboratory tests were made with the relay described above with satisfactory results. Figure 4 shows the connections for the completed relay. This diagram shows three resistors; R_1 is the shunting resistor of the foregoing discussion, while R_2 and R_3 are connected across the coils of the primary relays. These latter resistors are used to set the primary relays and to obtain smoother operation of the primary relays on the half-wave current. Telephone-type relays with copper slugs were used which further improved their operation on half-wave current. Selenium-rectifier elements were used, four stacks being connected in series to provide for the maximum reverse voltage which could be obtained. Figure 5 shows the completed relay. Figure 6 is an oscillogram for a symmetrical fault condition and shows the relay contacts of both primary relays closing within 1.14 cycles after the circuit was energized. Figure 7 is an oscillogram for a condition of inrush current, and shows the contacts of one relay closing, but no action on the second relay.

This relay scheme was put in service for the differential protection of a transformer which had been giving considerable trouble due to unnecessary operations of the differential relay on inrush currents. The setting used was 2.5 amperes for the primary relays with the desensitizer increasing the setting to 5.0 amperes. This relay has been giving satisfactory service and has eliminated unnecessary tripping due to inrush current and at the same time has provided a more sensitive setting for actual fault conditions.

It appears that the new relay described in this paper could be used advantageously in any application where saturation of current transformers may cause false tripping, such as bus differential and residual overcurrent relaying. Figure 8 shows a typical example of the effect of current-transformer saturation on residual relays. In this case, a residual relay was used on the 12-kv leads to a delta-

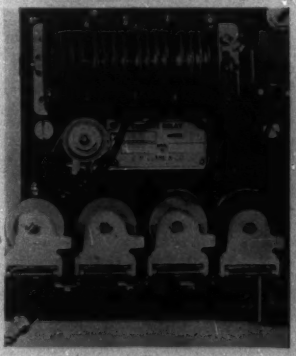

Figure 5. Completed relay

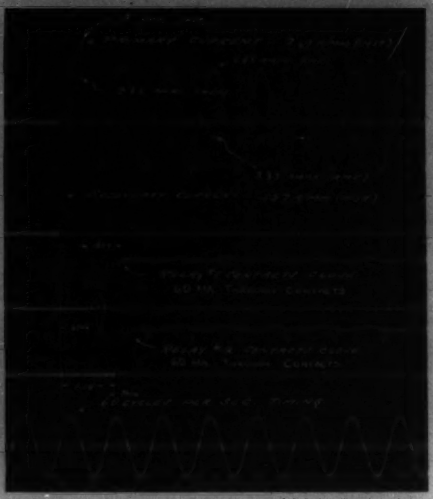

Figure 6. Operation of rectifier relay for symmetrical fault condition

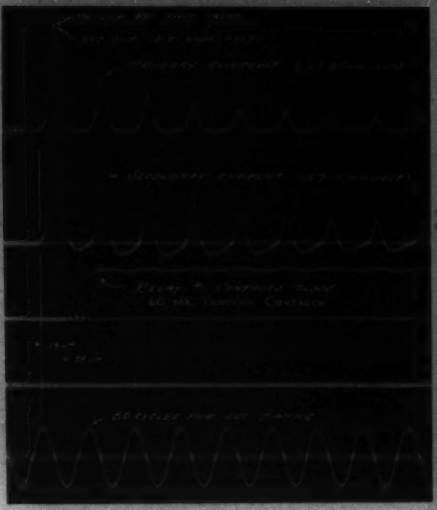

Figure 7. Operation of rectifier relay for inrush current

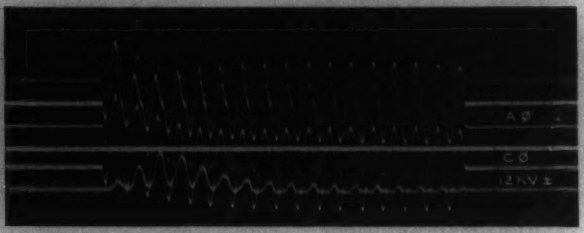

Figure 8. Oscillogram showing direct current through residual relay, with displaced fault current flowing in current transformers on *A* and *C* phases

connected transformer. When a phase-to-ground fault was placed on the high-voltage star-connected winding, a heavy displaced current appeared in two of the phase leads on the 12-kv side of the transformer. Unequal saturation of the two current transformers caused by the d-c component resulted in a considerable d-c residual current, as shown in the bottom trace of Figure 8. The rectifier relay would permit the use of an instantaneous sensitive setting without danger of tripping falsely for uses exemplified by Figure 8.

Conclusion

This paper describes a new relay for transformer protection and other applications, which will not operate on the pulsating direct current that appears to be caused by transformer inrush currents and other causes. This action is obtained by using two primary relays, one operating only on positive currents and the other only on negative currents. Under fault conditions, both relays operate and the faulted unit is tripped. If the current flows only in one direction, only one primary relay will operate and no tripping results.

References

1. Transformer Engineering (book), L. F. Blume. John Wiley and Son, Inc., New York N. Y.

2. Harmonic-Current-Restrained Relays for Transformer Differential Protection, C. D. Hayward. AIEE Transactions, volume 60, 1941, pages 377–82.

3. The Effect of Current-Transformer Residual Magnetism on Balanced-Current or Differential Relays, H. T. Seeley. AIEE Transactions, 1943, April section, pages 164–8.

4. Current Transformers and Relays for High-Speed Differential Protection, With Particular Reference to Offset Transient Currents, E. C. Wentz, W. K. Sonneman. AIEE Transactions, 1940, August section, pages 481–8.

Voltage and Current Relations for Controlled Rectification With Inductive and Generative Loads

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ELECTRONIC RECTIFIERS with controlled point of ignition are now used widely in various industrial-control and power-conversion systems. Although the principle of operation of thyratron and ignitron rectifiers is generally known, the analytical methods for calculation of d-c output voltages of rectifiers have been surprisingly incomplete. For example, the calculation of a d-c output voltage of a polyphase rectifier with no delay of the angle of ignition or with a slight delay only is a conventional matter, since the necessary formulas can be found in standard textbooks. When, however, the point of ignition of a polyphase rectifier is delayed beyond a certain critical value, the conventional formulas for d-c output voltages do not apply any more.

A problem of somewhat similar nature is encountered in the case of a single-phase half-wave rectifier where the conventional expression for the rectifier output voltage $E_{dc}=\sqrt{2}E_s/\pi$ applies to rectifiers with resistive loads only and is not valid in the case of an inductive load. An attempt to calculate the average value of the d-c load-terminal voltage for a single-phase half-wave rectifier with an inductive load becomes a rather complicated affair.

If in addition to a resistance and an inductance the load circuit of a polyphase rectifier with considerably delayed firing also includes a direct-voltage generating element such as the electromotive force of a running d-c motor, the relations become even more involved. The significance of highly delayed firing of rectifiers is apparent if one will consider their application to control and regulation of field currents of various rotating machines and as a controlled voltage supply for armatures of d-c motors in electronic adjustable-speed drives.

The problem of determining the output voltages of a p-phase rectifier with delayed ignition can be analyzed as two distinct cases with different relations involved in each case. The first is the rather well-known case where the current flowing in the load circuit has a continuous character: that is, at no time it drops to zero although it may contain a more or less pronounced a-c component. This is the case usually encountered in polyphase rectifiers with no delayed firing or when the firing is only slightly delayed.

If the firing, however, is delayed beyond a certain critical point, the current in any polyphase rectifier will become discontinuous: that is, it will consist of separate pulses so that within a certain portion of the cycle no current will flow in the load circuit. The conventional expressions for rectifier direct voltages are not valid in this case, and very little can be found in technical literature about the proper manner of attack of such a problem. This surprising gap undoubtedly is caused by the apparent complexity of relationships involved and the difficulty in adapting these relations to practical problems.

This paper presents an outline of generalized relations for average values of direct voltages of a p-phase rectifier for both cases of continuous and discontinuous conduction. The very natural question how to determine the critical point of ignition which separates the two cases is, of course, of particular interest, and this problem is given special consideration. A relatively simple method of calculation of direct voltages and currents described in this paper is illustrated by two examples.

Case of Continuous Conduction

The basic diagram of connections of a symmetrical p-phase rectifier with controlled point of ignition is shown in Figure 1, and the graph of the anode supply voltage and the d-c load voltage is given in Figure 2.

For a p-phase rectifier the phase displacement of two consecutive anode voltage waves (Figure 2) is

$$\varphi=\frac{2\pi}{p} \tag{1}$$

If the transformer leakage reactance is neglected, an instantaneous commutation will be obtained, and each rectifying element will conduct over the period from x_f to $x_f+2\pi/p$, where x_f is the point of ignition, and the average value of the rectifier output voltage (Figure 2) will be

$$E_{dc}=\frac{1}{\left(\frac{2\pi}{p}\right)}\int_{x_f}^{x_f+\frac{2\pi}{p}}\sqrt{2}E_s\sin x\,dx$$

or, after the integration,

$$E_{dc}=\frac{pE_s}{\sqrt{2}\pi}\left[\cos x_f-\cos\left(x_f+\frac{2\pi}{p}\right)\right] \tag{2}$$

Expression 2 is a different form of a well-known formula for the rectifier output voltage which can be found in textbooks. The introduction of the angle of ignition x_f in expression 2 seems advisable from the point of view of unification of different formulas for rectifier output voltages.

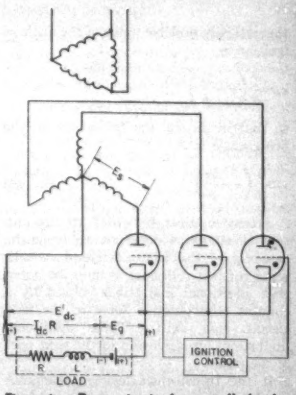

Figure 1. Power circuit of a controlled polyphase rectifier shown for the case $p=3$

If the arc drop of the rectifier E_a is taken into account, the rectifier output voltage will become

$$E_{dc}=\frac{pE_s}{\sqrt{2}\pi}\left[\cos x_f-\cos\left(x_f+\frac{2\pi}{p}\right)\right]-E_a \tag{3}$$

or

$$E_{dc}=\frac{pE_s}{\sqrt{2}\pi}\left[\cos x_f-\cos\left(x_f+\frac{2\pi}{p}\right)-a_a\frac{2\pi}{p}\right] \tag{3A}$$

where

$$a_a=\frac{E_a}{\sqrt{2}E_s}$$

Equation 3 also represents the direct voltage at the load terminals of the rectifier E_{dc}'. This is true also in the case where the load circuit contains an electromotive force opposing the flow of current. This apparently self-evident fact is mentioned here because, as it will be seen later, it does not apply to all cases of rectification.

From Figure 2 it becomes apparent that if the arc drop is neglected the minimum

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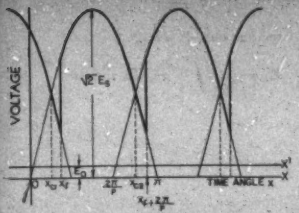


Figure 2. Anode supply voltage and d-c output voltage of a polyphase rectifier ($p=3$) with delayed ignition

Transformer leakage reactance neglected

theoretically possible value of the angle of ignition is

$$x_a=\frac{1}{2}\left(\pi-\frac{2\pi}{p}\right)$$

so that in general the limitation for the firing angle is

$$x_f>\frac{1}{2}\left(\pi-\frac{2\pi}{p}\right) \tag{4}$$

Attention must be called to the fact that limitation 4 does not apply in the case of $p=1$, that is, to a single-phase half-wave rectifier. Besides, it must be noted that additional limitations caused by a counter electromotive force in the load circuit may exist. These additional limitations are discussed in the next part of the paper.

If the transformer leakage reactance is taken into account the extinction of arc in the outgoing rectifying element (anode) will be delayed so that a definite commutation period will exist during which the two rectifying elements will conduct current simultaneously, and during this commutation period the load voltage will follow the average of the two anode voltages.[1] In this case the graph of the rectifier output voltage is as shown in Figure 3.

The effect of transformer reactance is part of the voltage regulation of the rectifier transformer and lowers the voltage output of the rectifier. This internal voltage drop of the transformer is directly proportional to the load current and to the reactance of the transformer, and is represented by the expression:[1]

$$\Delta E_{dc}=\frac{I_{dc}X_t E_{dc}}{2\sqrt{2}E_s \sin(\pi/p)} \tag{5}$$

where

I_{dc} = d-c load current
X_t = leakage reactance of transformer
E_s = a-c supply voltage (transformer secondary)
p = number of phases

It is evident from expressions 3 and 5 that in the case of continuous conduction the output voltage of the rectifier, that is, the voltage at the load terminals does not depend upon the inductance of the load nor upon any counter electromotive force which may be part of the load circuit (motor, battery).

Case of Discontinuous Conduction

If the angle of ignition is delayed beyond a certain critical point the current in the load circuit of the rectifier will become discontinuous: that is, it will drop to zero in the outgoing rectifying element before the incoming rectifying element will start conducting, so that there will be a definite period during which no current at all will flow in the load circuit.

This case has a particular significance wherever controlled rectifiers are used to supply a very wide range of load voltages such as in different control and regulating systems, rectifier motor drives, and the like.

Figure 4 represents a positive half of the anode supply voltage of a rectifier without any reference to the number of phases. It can be well understood that since no commutation in an ordinary sense will exist between the rectifying elements it is immaterial for the analysis of the individual current pulse whether it has been produced by a one-, two-, three-, or a p-phase rectifier.

Figure 4 is of particular importance since it illustrates a number of basic designations used in subsequent parts of this paper. All the electrical angles are referred to the initial 0 point as shown in the graph so that the equation of the anode supply voltage (with respect to zero line X) is

$$e=\sqrt{2}E_s \sin x$$

where E_s is the rms value of the a-c supply voltage and $x=\omega t$ the variable time angle.

The sum of the electromotive force (E_d) present in the load circuit and opposing the flow of current (Figure 4), such as the electromotive force generated in the armature of a rotating d-c motor, and of the constant arc drop of the rectifier E_a is represented by E_d

$$E_d=E_g+E_a \tag{6}$$

Obviously, the current flow in the load can be produced only by that portion of the anode supply voltage which rises above the constant voltage E_d so that in effect all the values of load current i and of the voltage drop caused by this current must be referred to a new zero line X'', shifted by E_d with respect to zero line X.

The angle of ignition, that is, the point at which the rectifying element starts conducting, is designated by x_f. The angle of extinction of the arc or the point at which the rectifier stops conducting is designated by x_z.

If for the sake of simplification it is assumed that the minimum starting voltage of the rectifier is equal to the arc drop, then it becomes apparent from Figure 4 that the range of the angles of ignition is

$$x_1<x_f<x_2 \tag{7}$$

If the voltage coefficient a is introduced,

$$a=\frac{E_d}{\sqrt{2}E_s}=\frac{E_g+E_a}{\sqrt{2}E_s} \tag{8}$$

the expressions for x_1 and x_2 will be as follows:

$$x_1=\sin^{-1}a \tag{9}$$

$$x_2=\pi-\sin^{-1}a \tag{10}$$

and the range of angles of ignition will be

$$\sin^{-1}a<x_f<\pi-\sin^{-1}a \tag{11}$$

When there is no electromotive force in the load circuit ($E_g=0$)

$$a=a_0=\frac{E_a}{\sqrt{2}E_s}$$

In this case the load voltages must be referred to the zero line X' (Figure 4).

For an ideal rectifier without any arc drop,

$$a=a'=\frac{E_g}{\sqrt{2}E_s}$$

and if there is no electromotive force in the load circuit, then $a=0$, and the maximum possible theoretical range of firing angles is

$$0<x_f<\pi$$

The analytical relationship between the angle of ignition x_f and the angle of extinction x_z as derived by Vedder and Puchlowski[3] is

$$\cos\theta \sin(x_z-\theta)-a+[a-\cos\theta \sin(x_f-\theta)]\epsilon^{-\frac{x_z-x_f}{\tan\theta}}=0 \tag{12}$$

where θ is the impedance angle of the load circuit that is

$$\tan\theta=\frac{\omega L}{R} \tag{13}$$

$$\cos\theta=\frac{R}{\sqrt{R^2+\omega^2L^2}} \tag{14}$$

R = resistance of the load circuit
L = inductance of the load circuit
$\omega=2\pi f$ (f = supply line frequency)

Although the equation 12 cannot be solved explicitly for x_z, the value of the angle of extinction can be calculated with satisfactory degree of accuracy for given values of x_f, θ, and a in accordance with the relatively simple method of gradual approximations which will be presented later in this paper.

Values of x_z as a function of x_f calculated from equation 12 are plotted in the form of several families of graphs in Figure 5.

All the curves of $x_z=f(x_f)$ for the same value of the coefficient a converge at a

point corresponding to $x_s = x_f = x_2$, as can be understood easily from Figure 4. All these points of convergence lie, of course, on the straight line *A-C* (Figure 5) which determines the maximum possible value x_2 of the angle of ignition x_f for a given value of coefficient a (expression 10). The straight line *A-B* determines the minimum possible value x_1 (expression 9) of the angle of ignition x_f for a given a.

It may be interesting to note that for the border case of a purely resistive load $L=0$ ($\cos\theta=1$) the angle of extinction x_s is solely a function of the coefficient a and is independent of x_f:

$$x_s = x_1 = \pi - \sin^{-1} a \tag{15}$$

as can be understood from Figure 4 or derived directly from equation 12.

For another border case of a purely inductive load $R=0$ ($\cos\theta=0$) equation 12

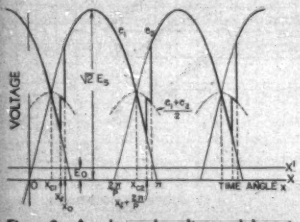


Figure 3. Anode supply voltage and d-c output voltage of a polyphase rectifier ($p=3$) with delayed ignition

Transformer leakage reactance considered

cannot be used to calculate x_s since, though it is fulfilled also in that case, it becomes an identity.

For $\cos\theta=0$ the value of x_s can be obtained from the following relationships:

For $a=0$ (rectifier without arc drop),

$$x_s = 2\pi - x_f \tag{16}$$

For $a>0$,

$$\cos x_s + a x_s = \cos x_f + a x_f \tag{17}$$

Equation 17 can be obtained directly from equation 20 for the condition $\cos\theta=0$, $I_{dc}R=0$.

Relationship 16 is represented in Figure 5 by the straight line *C-D*. Relationship 17 is also plotted in Figure 5 as part of each family of curves for a given value of coefficient a.

Figure 5 gives a clear picture of the maximum possible range of angles of ignition and angles of extinction for different coefficients a. As an example the maximum range of points of ignition x_f for $a=0$ is represented by *B-C* and for $a=0.8$ by *M-N*. Similarly, the maximum range of angles of extinction x_s for $a=0$ is represented by *B-D* and for $a=0.8$ by *M-K*. For $a=1$ the whole operating area of angles of ignition and extinction contracts into point *A*.

The average value of the rectifier output voltage E_{dc} can be calculated directly from Figure 4 by integrating the anode-voltage function with respect to zero line X' (taking into account the arc drop of the rectifier) over the period of conduction $x_s - x_f$ and averaging the result over the entire phase cycle $2\pi/p$,

$$E_{dc} = \frac{1}{\left(\frac{2\pi}{p}\right)} \int_{x_f}^{x_s} (\sqrt{2}\,E_g \sin x - E_0)\,dx$$

$$E_{dc} = \frac{pE_g}{\sqrt{2}\pi}[\cos x_f - \cos x_s - a(x_s - x_f)] \tag{18}$$

$$a = \frac{E_0}{\sqrt{2}E_g} \tag{19}$$

If the load circuit contains an electromotive force E_g opposing the direction of current flow (Figure 1) the average value of the $I_{dc}R$ voltage drop in the load (armature-voltage drop, for instance) can be calculated by integrating the voltage function with respect to zero line X' (Figure 4) over the conduction period of the rectifier $x_s - x_f$, and averaging the result over the phase cycle $2\pi/p$,

$$I_{dc}R = \frac{1}{\left(\frac{2\pi}{p}\right)} \int_{x_f}^{x_s} (\sqrt{2}\,E_g \sin x - E_d)\,dx$$

$$I_{dc}R = \frac{pE_g}{\sqrt{2}\pi}[\cos x_f - \cos x_s - a(x_s - x_f)] \tag{20}$$

where

$$a = \frac{E_d}{\sqrt{2}E_g} = \frac{E_g + E_0}{\sqrt{2}E_g}$$

The average direct voltage at the load terminals then will become

$$E_{dc}' = I_{dc}R + E_g$$

$$= \frac{pE_g}{\sqrt{2}\pi}[\cos x_f - \cos x_s - a(x_s - x_f)] + E_g$$

$$E_{dc}' = \frac{pE_g}{\sqrt{2}\pi}\left[\cos x_f - \cos x_s - a(x_s - x_f) + a'\frac{2\pi}{p}\right] \tag{21}$$

$$a' = \frac{E_g}{\sqrt{2}E_g} \tag{22}$$

When the load circuit does not contain any generative element, that is, $E_g=0$, then from expression 8 $a=a_0=E_0/\sqrt{2}E_g$, from expression 22 $a'=0$ and expressions 20 and 21 become identical with the expression 18. Hence, for $E_g=0$ the average direct voltage across the load terminals E_{dc}' is equal to the average direct-voltage drop in the load $I_{dc}R$ and equal to the rectifier output voltage E_{dc}

$$E_{dc}' = E_{dc} = I_{dc}R \tag{23}$$

for $E_g=0$

General Remarks on Voltage Relations

The comparison of expression 18 for the rectifier output voltage in the case of discontinuous current with expression 3A for the rectifier output voltage in the case of continuous current reveals that expression 3A can be regarded as a particular case of the general expression 18. Obviously, when the load current becomes continuous the angle of extinction x_s for a given rectifying element becomes equal to the commutation angle $x_f + 2\pi/p$ (Figure 2):

$$x_s = x_f + \frac{2\pi}{p} \tag{24}$$

By substituting expression 24 for x_s in equation 18, equation 3A is obtained.

Thus on the basis of previous considerations a following generalized scheme of relations can be set up:

1. The average value of the rectifier output voltage E_{dc} is represented by the general equation 18, which in the case of continuous current is transformed into equation 3A.

2. The average value of the load-terminal voltage E_{dc}' is represented by equation 18 in the case of R, L load and discontinuous current, and by equation 3A both for R, L, and R, L, E_g loads in the case of continuous current.

3. The average value of load-terminal voltage E_{dc}' is represented by equation 21 when the current is discontinuous and the load contains R, L, and E_g.

The case 3 stands out as a rather peculiar case in rectifier practice since here the load-terminal voltage is not equal to the rectifier output voltage. This situation normally is encountered where a rectifier is used to supply the voltage to the armature of a d-c motor, and to control the speed of the motor within a wide range by controlling the armature voltage. In general, the technical literature contains very little on the analytical aspects of this subject,[3] apparently because until recently the rectifier-motor drives had been in the stage of infancy, and only quite recent developments have aroused considerable interest in such systems.[4,5,6]

The fact that in the case of a generative load with discontinuous current the

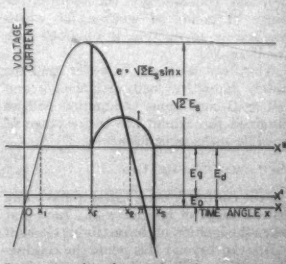


Figure 4. Anode supply voltage, load-terminal voltage, and load current referred to a single rectifying element

General case of a generative load (E_g)

load-terminal voltage is not equal to the rectifier output voltage can be understood even without any reference to analytical relations. Figure 4 shows clearly that during the nonconductive period of the rectifier the voltage at the load terminals is equal to the electromotive force generated in the load. On the other hand, the rectifier output voltage during the nonconductive period is equal to zero.

Thus, for the discontinuous conduction of a rectifier with load containing a countervoltage

$$E_{dc}' > E_{de} \tag{25}$$

Critical Point of Ignition

When the point of ignition of a rectifying element of a polyphase rectifier (Figure 2) is delayed beyond the firing point which may be called "critical point of ignition," the current in the load will become discontinuous; that is, each rectifying element will conduct an individual pulse of current, and there will be no commutation from one anode to the next anode.

It is apparent from Figures 2 and 4 that this critical point x_{fc} must satisfy the following equation:

$$x_s = x_{fc} + \frac{2\pi}{p} \tag{26}$$

$$x_{fc} = x_s - \frac{2\pi}{p} \tag{27}$$

and continuous conduction will be obtained when

$$x_f < x_s - \frac{2\pi}{p} \tag{28}$$

while the condition for discontinuous conduction is

$$x_f > x_s - \frac{2\pi}{p} \tag{29}$$

The higher is the value of the impedance angle of the load, the higher are the values of x_s (Figure 5) and x_{fc} (equation 27), and, consequently, the wider is the range of points of ignition for which continuous conduction is obtained (see condition 28).

This does not mean, however, that for purely inductive load with $\theta = \pi/2$ and $\cos\theta = 0$ continuous conduction will be obtained throughout the entire range of possible angles of ignition:

$$\sin^{-1} a < x_f < \pi - \sin^{-1} a$$

On the contrary, there exists a maximum critical angle of ignition $x_{fc\max}$ such that when the ignition of the rectifying element is delayed beyond this point the conduction always will be discontinuous, irrespective of how high the load inductance may be, that is, even for $\cos\theta = 0$.

This maximum critical point of ignition can be calculated under the assumption of purely inductive load ($\cos\theta = 0$) from equation 17 by substituting x_s from expression 26 into equation 17:

$$\cos\left(x_{fc\max} + \frac{2\pi}{p}\right) + a\left(x_{fc\max} + \frac{2\pi}{p}\right) = \cos x_{fc\max} + a x_{fc\max}$$

Hence,

$$x_{fc\max} = \sin^{-1}\frac{\pi a}{p \sin(\pi/p)} - \frac{\pi}{p} \tag{30}$$

where

$$\frac{\pi}{p} < \sin^{-1}\frac{\pi a}{p \sin(\pi/p)} \leq \pi \tag{31}$$

Equation 30 does not apply to $p = 1$, that is to single-phase half-wave rectifiers, since for these rectifiers the conduction is discontinuous for any possible firing angle.

For an ideal rectifier ($E_a = 0$) $a = 0$ (for an R, L load). Also, in many practical cases a is so small that it may be assumed equal to zero.

Then from expressions 30 and 31

$$x_{fc\max} = \pi - \frac{\pi}{p}$$

Since the range of possible firing angles is represented by the limitation 11 it is evident that when

$$x_{fc\max} \leq \sin^{-1} a \tag{32}$$

the current in the load will be discontinuous even for a purely inductive load ($\cos\theta = 0$) for any possible angle of ignition of the rectifier. From the relationship 32 one can calculate the critical value a_c of the coefficient a such that when $a > a_c$ the current always will be discontinuous for any possible angle of ignition.

From the relationships 32 and 30 the following equation for a_c is obtained:

$$\sin^{-1}\frac{\pi a_c}{p \sin(\pi/p)} - \sin^{-1} a_c = \frac{\pi}{p} \tag{33}$$

Hence

$$a_c = \frac{\sin(\pi/p)}{\sqrt{\sin^2(\pi/p) + \left(\cos(\pi/p) - \frac{\pi/p}{\sin(\pi/p)}\right)^2}} \tag{34}$$

where

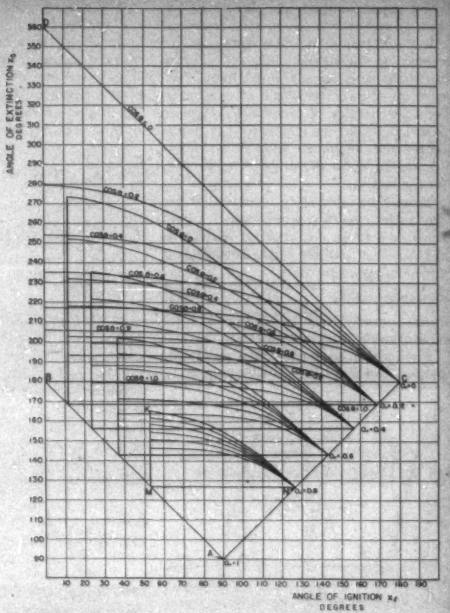
$p \neq 1$

Calculations of the Angle of Extinction—Method of Gradual Approximations

In the course of previous considerations the significance of the concept of the angle of extinction was fully emphasized. In order that fundamental expressions 18, 20, 21, and 27 can be used directly as practical formulas for calculations of the load-terminal voltage and for determination whether discontinuous or continuous conduction of the rectifier is obtained, a relatively simple and accurate method to determine x_s is necessary.

The basic equation 12 which represents the relationship between the angles of

Figure 5. System of graphs representing $x_s = f(x_f)$ for different values of parameters a and $\cos\theta$



ignition and extinction, transformer voltage and circuit constants, is a theoretically accurate analytical relationship, but it has the disadvantage that x_s cannot be expressed as an explicit function of x_f, a, and θ.

However, the following method of gradual approximations will permit to calculate x_s in a relatively simple manner with any required degree of accuracy.

The family of graphs shown in Figure 5 where x_s is plotted as a function of x_f for a set of values of a and $\cos\theta$ covering the entire range of $0<a<1$ and $0<\cos\theta<1$ can be used to determine directly by interpolation the first approximation x_s' of the angle of extinction.

Equation 12 can be represented as

$$\sin(x_s-\theta) = \frac{a-[a-\cos\theta\sin(x_f-\theta)]\epsilon^{\frac{x_s-x_f}{\tan\theta}}}{\cos\theta} \quad (35)$$

Introducing the following designations:

$$A = a-\cos\theta\sin(x_f-\theta) \quad (36)$$

$$B = \epsilon^{-\frac{\pi(x_s-x_f)}{180\tan\theta}} \quad (37)$$

$$M = \sin(x_s-\theta) \quad (38)$$

$$N = \frac{a-AB}{\cos\theta} \quad (39)$$

we obtain from equation 35

$$x_s = \sin^{-1}N+\theta \quad (40)$$

where $x_s \geq \pi-\sin^{-1}a$.

On the basis of the first approximation x_s' obtained from Figure 5 the values M' (equation 38), N' (equation 39), and x_{s1} (equation 40) are calculated. Then the second approximation of the angle of extinction x_s'' will be obtained from one of the three formulas, for one of the four possible conditions as specified in Table I.

The significance of expressions for x_s'' shown in Table I can be understood if attention is called to the fact that for $M'>N'$ the actual solution x_s of equation 35 is

$$x_s > x_s'$$

and for $M'<N'$

$$x_s < x_s'$$

and also that the value x_{s1} as compared to that of x_s' is indicative of the necessary degree of correction.

Very often the second approximation x_s'' will represent a sufficiently accurate solution of equation 12 (or 35). Usually, if the conditions are such that formula $x_s''=(x_s'+x_{s1})/2$ (Table I) was used to determine x_s'', the latter may be assumed to be a fairly close approximation of x_s. Otherwise, it is recommended to determine the third approximation x_s''' using x_s'' as a basis for calculation of M'' (equation 38), B'' (equation 37), N'' (equation 39), and x_{s2} (equation 40). Then, the third approximation x_s''' will be obtained from one of the three formulas as shown in Table II, analogous to Table I.

Obviously, this procedure can be carried on until the required degree of accuracy is obtained. In most practical cases, however, the second or third approximation yields sufficiently accurate results. For many estimating purposes even the first approximation x_s' obtained directly from Figure 5 may prove entirely adequate.

Examples

Two examples of calculations will be given here in order to emphasize the practical significance of previous considerations and illustrate the application of several basic formulas.

Example 1. Calculate the direct voltage at the load terminals and load current of a single-phase half-wave phanotron rectifier (no grid control) for the following set of conditions:

Rectifier supply voltage ..... $E_s = 110$ volts
Resistance of the load .. $R = 10$ ohms
Inductance of the load .. $L = 52$ millihenrys
Line frequency ..... $f = 60$ cycles per second
Rectifier arc-voltage drop ..... $E_a = 15$ volts

From equation 13,

$$\tan\theta = \frac{377\times0.052}{10} = 1.96$$

$$\theta = 62°58',\ \cos\theta = 0.4545$$

From equation 8,

$$a = a_0 = \frac{15}{\sqrt{2}\times110} = 0.0964$$

The angle of ignition from equation 9 (the rectifier without delayed ignition):

$$x_f = x_1 = \sin^{-1}0.0964 = 5°32'$$

From Figure 5 the first approximation of the angle of extinction for $a=0.0964$, $\cos\theta=0.4545$ and $x_f=5°32'$ is $x_s'=242°$. From equations 36, 37, 38, 39, and 40,

$$A = 0.0964-0.4545\sin(5°32'-62°58') = 0.4791$$

$$B' = \epsilon^{-\frac{\pi\times(242-5.53)}{180\times1.96}} = 0.122$$

$$M' = \sin(242°-62°58') = 0.0169$$

$$N' = \frac{0.0964-0.4791\times0.122}{0.4545} = 0.0835$$

$$x_{s1} = \sin^{-1}0.0835+62°58' = 238°11'$$

$$M'<N' \qquad x_{s1}<x_s'$$

Thus, the second and sufficient approximation (from Table I),

$$x_s'' = \frac{x_s'+x_{s1}}{2} = \frac{242+238°11'}{2} = 240°6'$$

The load-terminal voltage (from equation 21 for $a'=0$),

$$E_{dc}' = \frac{110}{\sqrt{2}\pi}\left[\cos5°32'-\cos240°6'-0.0964\left(\frac{\pi\times240.1}{180}-\frac{\pi\times5.53}{180}\right)\right] = 27.2 \text{ volts}$$

and the load current ($E_{dc}'=I_{dc}R$ for $a'=0$),

$$I_{dc} = \frac{E_{dc}'}{R} = \frac{27.2}{10} = 2.72 \text{ amperes}$$

Example 2. A three-phase controlled rectifier is supplying the power to the armature of a one-horsepower 230-volt four-ampere 850-rpm d-c motor. Calculate the armature current, the armature voltage, and the theoretical rectifier output voltage, assuming that the ignition of the rectifier is delayed to be $x_f=110°$ and that the motor is running at the rated speed.

The following figures are known:

Transformer voltage .... $E_s = 350$ volts, $\omega = 377$
Armature resistance .... $R = 3$ ohms
Armature inductance .... $L = 70$ millihenrys
Rectifier arc drop ..... $E_a = 15$ volts

Table I

	$M'>N'$	$M'<N'$
$x_{s1}>x_s'$	$x_s''=\frac{x_s'+x_{s1}}{2}$	$x_s''=x_s'-\frac{x_{s1}-x_s'}{2}$
$x_{s1}<x_s'$	$x_s''=x_s'+\frac{x_s'-x_{s1}}{2}$	$x_s''=\frac{x_s'+x_{s1}}{2}$

Table II

	$M''>N''$	$M''<N''$
$x_{s2}>x_s''$	$x_s'''=\frac{x_s''+x_{s2}}{2}$	$x_s'''=x_s''-\frac{x_{s2}-x_s''}{2}$
$x_{s2}<x_s''$	$x_s'''=x_s''+\frac{x_s''-x_{s2}}{2}$	$x_s'''=\frac{x_s''+x_{s2}}{2}$

At rated speed the electromotive force of the motor,

$$E_g = 230 - 4 \times 3 = 218 \text{ volts}$$

From equation 13,

$$\tan \theta = \frac{377 \times 0.07}{3} = 8.8$$

$$\theta = 83°32', \quad \cos \theta = 0.1126$$

From equation 8,

$$a = \frac{218 + 15}{\sqrt{2} \times 350} = 0.471$$

From equation 19,

$$a_0 = \frac{15}{\sqrt{2} \times 350} = 0.0303$$

From Figure 5 the first approximation of the angle of extinction for $a = 0.471$, $\cos \theta = 0.1126$ and $x_f = 110°$ is

$$x_1' = 183°$$

Thus, from equations 36, 37, 38, 39, and 40,

$$A = 0.471 - 0.1126 \sin (110° - 83°32') = 0.4209$$

$$B' = \epsilon^{-\frac{\pi \times (183 - 110)}{180 \times 8.8}} = 0.865$$

$$M' = \sin (183° - 83°32') = 0.9864$$

$$N' = \frac{0.471 - 0.4209 \times 0.865}{0.1126} = 0.95$$

$$x_{n1} = \sin^{-1} 0.95 + 83°32' = 191°43'$$

Since

$$M' > N', \quad x_{n1} > x_1'$$

then from Table I the second approximation

$$x_1'' = \frac{x_1' + x_{n1}}{2} = \frac{183° + 191°43'}{2} = 187°21'$$

The corrected values B'', M'', N'', and x_n are

$$B'' = \epsilon^{-\frac{\pi \times (187.35 - 110)}{180 \times 8.8}} = 0.858$$

$$M'' = \sin (187°21' - 83°32') = 0.9711$$

$$N'' = \frac{0.471 - 0.4209 \times 0.858}{0.1126} = 0.9775$$

$$x_n = \sin^{-1} 0.9775 + 83°32' = 185°42'$$

Here $M'' < N''$ and $x_n < x_1''$ and from Table II the third approximation,

$$x_1''' = \frac{x_1'' + x_{n1}}{2} = \frac{187°21' + 185°42'}{2} = 186°32'$$

The critical point of ignition (equation 27),

$$x_{fc} = 186°32' - \frac{180 \times 2 \times \pi}{\pi \times 3} = 66°32'$$

Hence, it is apparent that $x_f > x_{fc}$ and a discontinuous conduction is obtained.

To calculate the armature current one must refer to formula 20 or 21.

From formula 20,

$$I_{dc}R = \frac{3 \times 350}{\sqrt{2}\pi}\left[\cos 110° - \cos 186°32' - 0.471\left(\frac{\pi \times 186.53}{180} - \frac{\pi \times 110}{180}\right)\right]$$

$$= \frac{3 \times 350 \times 0.02}{\sqrt{2}\pi} = 4.72 \text{ volts}$$

Hence the armature current,

$$I_{dc} = \frac{4.72}{3} = 1.57 \text{ amperes}$$

The armature voltage (load-terminal voltage),

$$E_{dc} = E_g + I_{dc}R = 218 + 4.72 = 223.72 \text{ volts}$$

Obviously, the value of E_{dc}' could be calculated directly from equation 21, and the same result would be obtained.

The rectifier output voltage from equation 18,

$$E_{dc} = \frac{3 \times 350}{\sqrt{2}\pi}\left[\cos 110° - \cos 186°32' - 0.0303\left(\frac{\pi \times 186.53}{180} - \frac{\pi \times 110}{180}\right)\right] = 144.3 \text{ volts}$$

This voltage, of course, is a purely theoretical one and cannot be measured directly. Thus the relationship 25 is confirmed.

If in the course of calculations the angle of ignition would be found smaller than the critical angle of ignition x_{fc}, it would mean that continuous conduction is obtained, and the armature voltage, equal to the rectifier output voltage, would be calculated from equation 3 or 3A.

Usually, the conditions for continuous or discontinuous current 28 and 29 can be checked by using the first approximation of the angle of extinction taken directly from graphs in Figure 5.

Conclusions

The generalization of expressions for the rectifier output voltage and load-terminal voltage to cover all cases of controlled rectification for both continuous and discontinuous conduction and for any number of phases seems to be of particular significance. Clear distinction between the concepts of the rectifier output voltage and the load-terminal voltage is necessary, particularly in the case of discontinuous conduction with a generative load. The determination of the critical angle of ignition, separating the cases of continuous and discontinuous conduction, is of great importance when dealing with rectifiers with a wide range of firing.

Circuit constants have a predominant effect on both load-terminal voltage and the output voltage of a rectifier operating with discontinuous conduction.

The method of calculation of angles of extinction discussed in this paper enables to use relatively simple formulas for average values of direct voltages. As the examples have shown, this method permits to perform the calculations efficiently and without any reference to complicated relationships.

List of Symbols

A = term (equation 36)
a = voltage coefficient (equation 8)
a_0 = voltage coefficient (equation 19)
a' = voltage coefficient (equation 22)
a_c = critical value of voltage coefficient (equation 34)
B = term (equation 37)
E_s = rms supply voltage (transformer secondary)
E_{dc} = rectifier output voltage (average value)
E_{dc}' = load-terminal voltage (average value)
E_g = direct voltage generated in load circuit (opposing electromotive force)
E_a = arc-voltage drop of rectifier
$E_d = E_g + E_a$
e = instantaneous value of anode supply voltage
I_{dc} = rectifier load current (average value)
L = inductance of load circuit (in henrys)
M = term (equation 38)
M', M'', M''' = intermediate values of term M
N = term (equation 39)
N', N'', N''' = intermediate values of term N
p = number of phases (secondary)
R = resistance of load circuit
$x = \omega t$ = variable time angle
x_f = angle of ignition (firing)
x_1 = minimum possible angle of ignition
x_2 = maximum possible angle of ignition
x_{fc} = critical angle of ignition
$x_{fc\,max}$ = maximum critical angle of ignition
x_e = angle of extinction
x_1', x_1'', x_1''' = first, second, third approximations of the angle of extinction
x_{n1}, x_{n2}, x_{n3} = intermediate values of the angle of extinction (equation 40)
θ = impedance angle of load circuit
$\omega = 2\pi f$ = angular line frequency
$\pi = 3.1416$
$\epsilon = 2.7183$

References

1. Gaseous Conductors, J. D. Cobine. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1941. Pages 494–9.

2. Theory of Rectifier—D-C Motor Drive, E. H. Vedder, K. P. Puchlowski. AIEE Transactions, volume 62, 1943, pages 863–70.

3. Rectifier-Circuit Duty, C. C. Herskind. AIEE Transactions, volume 63, 1944, March section, pages 123–8.

4. Electronic Control of D-C Motors, K. P. Puchlowski. AIEE Transactions, volume 62, 1943, pages 870–7.

5. Thyratron Motor Control, E. E. Moyer, H. L. Palmer. AIEE Transactions, volume 62, 1943, November section, pages 706–12.

6. Behavior Factors of Rectifier-Driven D-C Motors, Victor Siegfried. AIEE Transactions, volume 63, 1944, July section, pages 530–2.

7. Applied Electronics, electrical engineering staff of Massachusetts Institute of Technology. John Wiley and Sons, Inc., New York, N. Y., 1943.

Improved Fault Protection for Rural Distribution Systems

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Synopsis: The use of automatic oil circuit reclosers on rural distribution lines has resulted in improved continuity of service as well as reduced maintenance cost. However, automatic circuit reclosers now in use are limited in application because of their inability to co-ordinate properly with fuses on the load side of the reclosers. An improved oil circuit recloser has been designed to incorporate the advantages of minimum time-delay opening on the first and second operations to clear all transient faults on the protected section, and greater time-delay opening on the third and fourth operations to allow the blowing of a sectionalizing or transformer fuse to isolate a permanent fault without causing a lockout of the recloser. A description is given of the design, operation, and advantages of this recloser which permits clearing of all transient line faults and isolates permanent faults by properly co-ordinating with sectionalizing fuses.

Improved Equipment Is Required

RURAL distribution systems with their long lines and small loads scattered over large areas depend, for their economical operation, upon low cost of installation, minimum cost of maintenance, and maximum continuity of service.

With the expansion of these systems and the consequent greater cost of service trips, the need has arisen for improved low-cost equipment which is capable of decreasing the number of outages thereby reducing the maintenance cost.

Experience has proved that approximately 85 per cent of all faults occurring on rural systems are of a temporary nature; consequently, the desired protective equipment not only must be able to clear all faults but also should be able to restore service completely after all temporary faults and to isolate the permanent faults to the smallest possible localities.

While automatic circuit reclosers, if properly designed to co-ordinate with one another, can be used advantageously at all sectionalizing points, the low revenue of most of the short branches usually will prohibit such universal use, and it is therefore desirable that inexpensive fuse cutouts be retained on the system.

The ideal combination of protective equipment thus will permit the use of simple fuse cutouts on the smaller branches to isolate the permanent faults occurring there and will make use of automatic circuit reclosers at the feeders and more important sectionalizing points to clear all temporary faults and to isolate permanent faults occurring between the recloser and the fuses.

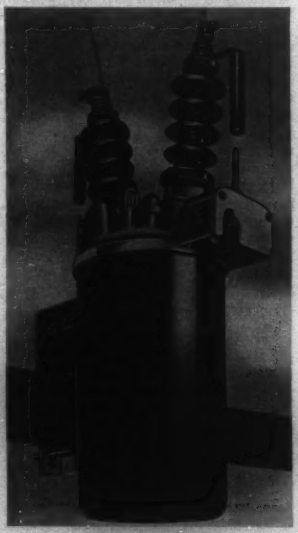

Figure 1. Single-pole automatic oil circuit recloser

To make this selective action possible, the automatic circuit recloser must be of an improved design and meet the following requirements:

1. It must have at least a first operation with a time–current characteristic which is faster than that of the fuse or fuses which it protects, so that the fault will not damage the fuses.

2. It must have at least one subsequent operation with a time–current characteristic which is considerably slower than that of the fuses which it protects, so that the fuse protecting the faulted line will blow.

3. It must, after a minimum of these two operations, lock out in the open position so that, if a permanent fault occur on that part of the system protected only by a recloser, the recloser will isolate this fault from the system.

4. It must be reliable in its operation, light in weight, and low in cost in order to hold the maintenance and installation costs to a minimum.

To meet the foregoing requirements a new automatic oil circuit recloser has been developed as shown in Figure 1.

General Construction

This automatic circuit recloser consists of an aluminum cover and a steel tank, which may be grounded in a conventional manner. A steel hanger welded to the tank permits single-bolt pole mounting, and a simple bracket provides for crossarm mounting. Two conventional porcelain bushings are used so that the line terminals are the only external live parts. Spark gaps are mounted beside each bushing so that surge voltages cannot damage the recloser. The operating handle and the counter are covered by a hood to protect them from sleet. The position of the handle is up when the recloser is closed and down when the recloser is open. All operations are recorded on a counter, and all but the lockout operations are independent of the operating handle, which, in a downward position, indicates that the recloser is permanently locked out. An oil-level gauge is located on the cover.

Operational Features

This automatic circuit recloser requires four consecutive operations to lock out.

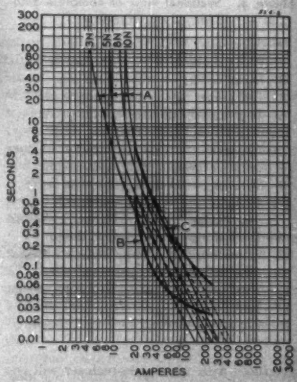

Figure 2. Clearing-time–current curves for ten-ampere automatic oil circuit recloser and melting- and clearing-time–current curves for co-ordinating fuse links

A—100-per-cent-rated fuse links
B—First and second operations
C—Third and fourth operations

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The first two of these have a time-current characteristic which is considerably faster than that of fuses having the same rating. The last two operations are time delayed and have a time-current characteristic which is approximately the same as that of fuses having the same rating.

Clearing time-current curves for a ten-ampere automatic circuit recloser and melting and clearing time-current curves

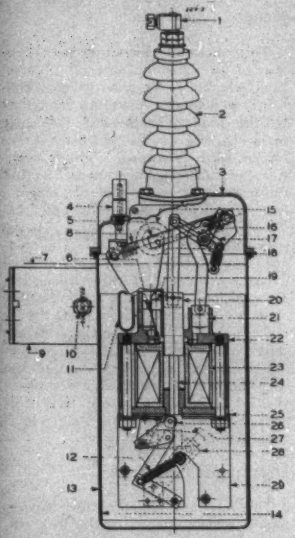

Figure 3. Sectional view of complete automatic oil circuit recloser

1—Terminal	16—Operating mechanism
2—Porcelain bushing	17—Hand trip mechanism
3—Metal cover	18—Cover gasket
4—Oil gauge	19—Slide valve
5—Toggle mechanism	20—Solenoid plunger
6—Trip piston	21—Pump piston
7—Oil level	22—Solenoid frame
8—Lockout spring	23—Series coil
9—Mounting bracket	24—Plunger extension
10—Ground connector	25—Coil shield
11—Thermal trip	26—Contact - mechanism roller
12—Contact operating spring	27—Stationary contact
13—Steel tank	28—Moving contact
14—Tank liner	29—Contact frame
15—Operating handle	

for fuses with which the recloser will coordinate are shown in Figure 2. It can be seen that properly selected fuses will remain undamaged upon the occurrence of a fault and that the recloser will open the circuit to clear the fault. If the fault exist after reclosing, the recloser will open the circuit again in the same manner. If the fault exist after the second reclosure, the recloser will operate after a greater time delay and will blow the properly selected fuse, thus isolating the fault to the smallest protected section. The recloser can operate still a fourth time to be certain the fuse will clear, and, if the fault is not protected by a fuse, the recloser will open and lock out to clear the fault from the system.

Automatic circuit reclosers of different ratings will co-ordinate with one another as well as with fuses.

Figure 3 shows in sectional view the main elements of this automatic circuit recloser. Essentially, these consist of three assemblies, namely: the operating mechanism with lockout spring-and-toggle mechanism mounted in the cover, the hydraulic mechanism and the series coil suspended below the cover, and the contact mechanism mounted below the series coil.

It will be seen that the upward movement of the operating handle elongates the lockout spring while at the same time it permits the toggle mechanism to arrive at an over-center position thus storing the energy of the lockout spring for the lockout operation. It also will be seen that the downward movement of the operating handle trips the toggle mechanism to release the stored energy in the lockout spring and open the recloser until the operating handle is again moved upward.

Figure 4 is a schematic cross section of the hydraulic mechanism, which aids in explaining its operation. The hydraulic system serves four separate functions:

1. It trips the recloser to the lockout position after the fourth operation in any group of successive operations.

2. It accounts for the time delay of inverse characteristic on the third and fourth successive operations.

3. It introduces a reclosing delay of one second between operations to insure the complete dissipation of ionized gasses.

4. It recycles the recloser when the fault is cleared or isolated.

The hydraulic system operates as follows. Upon the occurrence of an overload or fault, the solenoid plunger is drawn into the series coil. The plunger extension acts upon the contact-mechanism roller and, through a set of links, extends the two contact operating springs. When the solenoid plunger arrives at its nearly final position, the contact-mechanism roller imparts a blow to the movable contacts and at the same time brings the hinge point of the contact operating springs to an over-center position so as to cause a rapid contact separation. During this first downward movement of the solenoid plunger the entrapped oil escapes through an escape port by lifting a slide valve in the hydraulic mechanism, as can be seen in Figure 4. Simultaneously with the downward movement of the solenoid plunger a pump piston is moved within a cylinder to force a predetermined quantity of oil below a trip piston.

During the second operation of the recloser, the entrapped oil below the solenoid plunger again escapes freely through the escape port, while the trip

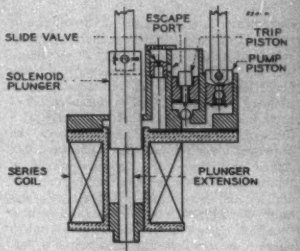

Figure 4. Sectional view of hydraulic mechanism

piston rises to such a position as to close this escape opening at the finish of the second operation.

With the escape port closed off during the third and fourth operations, the downward travel of the solenoid plunger is retarded, because the escape of entrapped

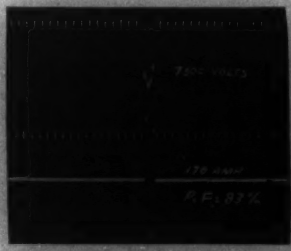

Figure 5. Interruption of 170 amperes at 7,500 volts and power factor of 93 per cent on five-ampere recloser

oil is possible only by leakage along the solenoid plunger. As the trip-out piston rises higher with each successive operation of the breaker, it not only closes the escape port at the end of the second operation but also continues to rise during the third and fourth operations, and at the end of the fourth operation it contacts the insulated toggle link to trip the toggle and thus release the energy stored in the lockout spring, which causes the recloser to open and lock out.

The energy stored in the contact operating springs during the downward movement of the plunger is not consumed entirely in separating the contacts. It also

Figure 6. Four interruptions of 75 amperes at 7,500 volts and power factor of 82.5 per cent on ten-ampere recloser

acts to return the solenoid plunger to its uppermost position and, after doing this, returns the moving contact to the closed position with a snap action. The upward movement of the plunger therefore constitutes the time delay between successive operations. It is retarded, because the slide valve in the hydraulic mechanism closes off the escape port and only permits oil to enter through a small opening in its top.

It will be noted from Figure 4 that the trip piston is provided with a valve which permits a slight leakage of oil so that this piston slowly will resettle to its original position. Thus, if a fault be cleared after any operation, the recloser automatically will reset itself for a complete cycle of successive operations. The total time for this to take place after a lockout operation has occurred is approximately one minute and thus approximately 15 seconds per operation.

The oil used in the automatic circuit recloser is of a low viscosity which will not change greatly with decrease in temperature. As the time required for the blowing of a fuse link is also dependent upon ambient temperatures, the retardation of the oil circuit recloser by lower temperatures will be minimized. While extremely low temperatures will have an effect upon the time–current curves of the automatic oil circuit recloser, this deficiency is well offset by the advantages of the hydraulic mechanism, in that it can take great shock and eliminates ratchets, gears, and latches which are less sturdy and dependable. It constitutes a simple means to vary the time delay by allowing the free escape of oil during the first and second operations and by restricting the escape of oil during the third and fourth operations.

The contact mechanism is a unitary structure which is removed readily and replaced. It employs a double set of contacts to eliminate the use of braids or flexible leads. As previously explained, the opening or closing of these contacts can be effected only by a complete downward or upward stroke of the solenoid plunger, consequently, partial opening of the contacts, or so-called telegraphing, is impossible. The separating of the contacts is initiated by the final downward movement of the plunger, which imparts a blow to them in proportion to the current value to be interrupted, while the total separation of the contacts is accomplished by the contact operating springs. After the return of the solenoid plunger to its uppermost position, the contacts reclose with a snap action. Contacts are made of copper tungsten which insures long life by its ability to withstand arcing.

The recloser coils are so designed that minimum tripping current for any size recloser produces the same number of ampere turns and thus the same force upon the plunger. This permits changing reclosers to any rating merely by changing coils. As will be noted in Figure 3, replacement of coils requires no loosening of linkages or disturbing of the contact mechanism. Coils are made in normal ratings of 5, 10, 15, 25, and 50 amperes for minimum trip-current values of 10, 20, 30, 50, and 100 amperes. The interrupting capacities are 150, 250, 375, 600, and 1,200 amperes respectively.

Time current values have been obtained from oscillographic records of interruptions. Figure 5 shows an oscillogram of a single interruption at 7,500 volts and 170 amperes on a five-ampere recloser at a power factor of 83 per cent. Figure 6 shows an oscillogram of four operations with lockout on a ten-ampere recloser at 7,500 volts with a 75-ampere fault current at a power factor of 82.5 per cent.

It will be noted that a thermal trip is provided which will, upon excessive oil temperature, move the insulated toggle link and trip the toggle to release the stored energy of the lockout spring, thus causing a recloser lockout operation.

In the design of this recloser it was found possible to reduce the total weight to approximately 65 pounds and the quantity of oil to approximately $2\frac{1}{2}$ gallons, while the required internal and external flashover values were maintained.

Summary

The important improvement of this automatic circuit recloser is its double time–current characteristic. As previously explained, this will permit the use of fuses on small branches of the system so as to keep the initial cost to a minimum. Upon the occurrence of a temporary fault this new recloser will clear the fault and restore service immediately afterwards, and upon the occurrence of a permanent fault will cause the fuse link to blow.

If reclosers are used on feeders and main branches, and if fuses are used for all short branches, the use of this improved-type automatic circuit recloser will result in considerable saving in maintenance cost, because it will reduce the number of service trips. It will reduce customer outages to a minimum and confine the fault to the smallest practical locality.

Study of A-C Sheath Currents and Their Effect on Lead-Cable-Sheath Corrosion

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Synopsis: The destruction of lead sheaths on underground cables by electrolysis usually is caused by the action of direct currents which originate from one or several well-defined sources. Little information is available concerning a-c electrolysis, and since the extent of its destructive action is less widespread than that produced by direct current it is considered generally to be relatively less important in the field of cable-sheath corrosion. This paper discusses two cases of electrolysis in which the lead sheaths on single-conductor power cables were corroded through, causing cable breakdowns; and describes field observations and laboratory tests which show that at first the corrosive action was accelerated greatly by rectified alternating currents which were induced in the sheaths by the load current. A method of protecting the sheaths against such electrolytic corrosion also is described.

THE GENERAL PROBLEM of lead-cable-sheath corrosion is a familiar one to any industrial organization whose field of activity involves the extensive use of lead-covered cables. This is particularly true of communication and electric-power companies. One of the earlier and most common forms of electrolytic corrosion is that caused by the accumulation of stray direct currents by underground cables traversing areas served by transit lines which are discharged back to earth in sections where the cables are positive with respect to ground. Destruction of the cable sheaths in the positive areas where current leaves the cable is known as anodic corrosion. Other factors, more recently recognized, include chemically developed earth potentials resulting from unfavorable soil conditions, galvanic potentials produced by dissimilar metals, and irregularities in the lead sheath itself.

Figure 1. Two specimens of corroded lead sheaths

Electrolysis caused by alternating current has never received widespread consideration, and the consensus of opinion among many authorities has been that it is a complicated phenomenon and is usually unimportant, particularly where sheath sectionalization, with single grounding point, is used.

Two Cable Failures

That a-c corrosion can be of considerable importance is demonstrated by the fact that the case histories of two insulation failures on 13-kv single-conductor lead-covered power cables show that the breakdowns were the result of corrosion produced by a combination of galvanic current and rectified alternating sheath currents. In both cases a one-eighth-inch lead sheath was corroded through, permitting water which was present in the cable ducts to enter and eventually cause insulation failure. Neighboring cables were badly pitted and it was necessary to either replace these or provide protection against further corrosion.

The phenomenon of a-c corrosion was found by extensive field and laboratory tests to be attributable to a process of rectification in which alternating voltages of low value induced in the sheaths by the load current in the cables resulted in alternating currents between sheaths and ground; these were converted to direct currents which produced anodic corrosion. The initial failure occurred in 1937 on a 1,750,000 circular mils paper-insulated single-conductor power cable which was one of eight used to connect a 13,300-volt 25-cycle single-phase 35,000-kva generator in the main generating station at Safe Harbor to the 13-kv bus in adjacent Conestoga substation. The cables are connected four in multiple per phase and are approximately 1,600 feet long. They normally carry a total load of about 2,600 amperes. Each lead sheath is sectionalized at three locations; this results in four approximately equal lengths which are insulated from each other with sheath insulators to prevent the circulation of sheath currents. Individual sheath sections are bonded at only one point to a nearby copper ground bus and sheath voltages are limited to 12 volts per section at normal loading. The cables are installed in eight individual fibre ducts, in a concrete bulkhead. Seven hundred feet of the cable run lie within a tunnel cut through a rock formation of mica schist, which is stratified and porous, permitting water to seep into the tunnel and subsequently into the cable ducts. This provides a low-resistance path to ground from the sheaths and facilitates the action of corrosion. Figure 1 shows two specimens of pitted cables.

The second and most recent failure occurred in November 1943, on a single-conductor 13,200-volt paper-insulated 1,500,000 circular mils cable connecting a 33,750-kva three-phase 60-cycle outdoor transformer to the 13-kv bus in the Holtwood plant of the Pennsylvania Water and Power Company. The cable is one of a group of six, each approximately 290 feet long, connected two per phase. Each cable is installed in a separate fiber

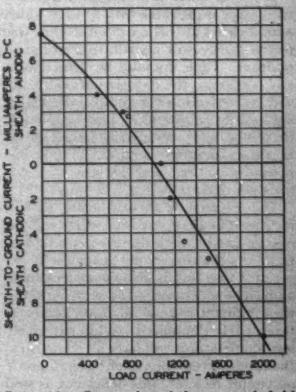

Figure 2. Curve plotted from actual field measurements showing reversal of d-c polarity with increasing load current

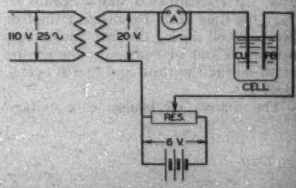

Figure 3. Circuit used for tests on corrosion cells

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duct laid in a concrete envelope surrounded by a solid wall of porous rock or earth fill. Here again seepage water drains into the ducts and creates a condition of low resistance from sheath to ground, which, in effect, shunts the single metallic ground connection on the lead sheath at the outdoor-cable pothead and forms a path for corrosion currents to flow from the sheath to ground for the entire duct length.

Field Observations

Samples of water removed from the ducts at both Safe Harbor and Holtwood were high in alkalinity, having pH values from 9.5 to 11.6. Analyses showed that sodium carbonate, sodium bicarbonate, calcium carbonate, and sodium hydroxide were present. In solution these chemicals provide an excellent electrolyte for the generation of galvanic currents between the sheaths and the nearby copper ground wire, and because of their low resistance the magnitude of both the galvanic and rectified currents was increased. A water sample from the ducts at Holtwood had a specific resistance of only 115 ohms per cubic centimeter as compared with 7,800 ohms for Baltimore city water. Resistance of individual cable sheaths to station ground was as low as 2.7 ohms with the metallic ground connection removed. In a dry installation of fiber duct a resistance to ground of the order of megohms may be expected.

The cables at Safe Harbor lie within several feet of a copper ground bus which runs parallel to them embedded in the tunnel concrete. The water-soaked concrete and fiber duct act as an electrolyte between the lead cables and copper ground wire, so that with no power flow through the cables a small direct potential is present; in effect lead sheath and copper ground constitute a galvanic cell with the copper ground wire as the positive electrode. That is, the copper is positive with respect to the sheaths at the grounding points outside the ducts, with the metallic ground connection removed. There are no stray direct currents in the areas to complicate the situation, and the nearest street-car lines are many miles distant. With the cables de-energized, direct currents up to eight milliamperes were measured flowing between one cable sheath and ground, with the cable anodic, that is, current flow was away from the cable into the wet concrete. This was galvanic current produced by the potential difference between lead sheath and copper ground wire.

Table I

Section	Cables De-energized	Cables Carrying 2,600 Amperes Total Current
1	0.85 milliampere, sheath −	0.3 milliampere, sheath −
2	1.1 milliamperes, sheath −	1.85 milliamperes, sheath +
3	0.1 milliampere, sheath −	0.7 milliampere, sheath −
4	2.7 milliamperes, sheath −	12.0 milliamperes, sheath −

Further observations showed that the direct currents varied in magnitude when varying load current flowed in the cables, and even in some instances reversed their polarity as the load current increased above a certain value. The measurements shown in Table I made at the normal grounding points between sheath and ground bus are representative of direct currents in the four individual sections of the faulted cable, after repairs were made, section 4 now being new cable.

It is seen that the load current had the effect of increasing the direct current in two cases, reducing it in one case, and actually reversing it in another.

Figure 2 represents graphically a case at Safe Harbor in which the sheaths of eight cables were tied together and the direct current measured through the common wire to ground. It is seen that at no load the current is 7.5 milliamperes with the sheaths anodic, and above 1,000 amperes total load the polarity reverses making the sheaths cathodic.

In searching for a possible cause for the variation of the direct currents the most significant clue was the change in their magnitude with changes in load current, and consequently with the induced alternating sheath currents. It was decided to investigate the possibility of these alternating currents being converted into direct current through some process of rectification. Accordingly, a series of laboratory tests were undertaken which extended over a period of nearly a year, and it was found that alternating currents are rectified in lead–copper electrolytic cells using water from the cable ducts as an electrolyte, with resultant destruction of the lead. Such cells are believed to be laboratory analogies of field conditions.

Laboratory Studies

Laboratory experiments were conducted on lead–copper cells to observe the effectiveness of the counter-potential method for preventing sheath corrosion, and to study the factors which affect the rectification phenomenon found on the cables. The experiments were divided into two main groups:

(*a*). A-c corrosion studies.
(*b*). Rectification studies.

Corrosion Study

Electrolytic cells were constructed of glass laboratory jars $2^1/_2$ by 4 inches by 6 inches deep, with lead and copper electrodes in an electrolyte of water from the cable ducts. Samples of water were used having pH values from 8.2 to 9.5, and specific resistance of 450 ohms per cubic centimeter. In these tests the loss of weight of the electrode was used as a measure of the degree of corrosion. Cell *A* was energized continuously at low voltage with 25-cycle current only, using one-half ampere initially and reducing later to one-tenth ampere. Two other cells were energized with 25-cycle current, with ten milliamperes direct current superimposed. In one of these, cell *B*, the direct current was applied in the direction to

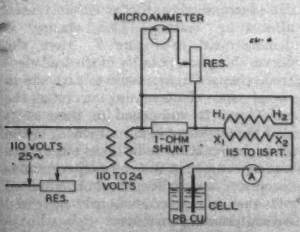

Figure 4. Circuit used for measuring rectified current

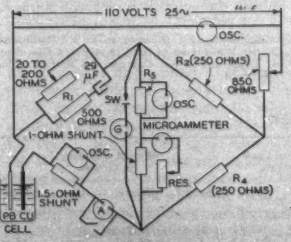

Figure 5. Circuit used for taking oscillograms of rectified current

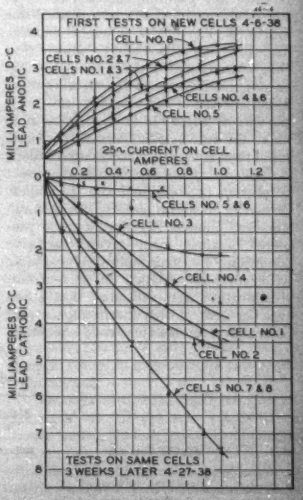

Figure 6. Rectified current versus applied alternating current on new and aged cells

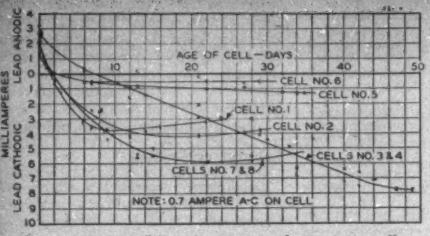

Figure 7 (above). Effect of aging on rectification in test cells

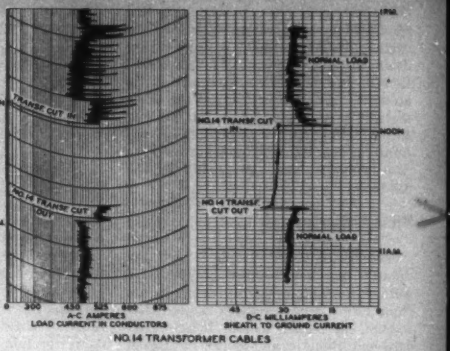

Figure 8 (right). Synchronized charts showing effect of changes in load current on d-c sheath-to-ground current

make the lead electrode cathodic; in cell *C* the lead was made anodic. The magnitude of alternating and direct currents was held at the same value on all cells. Porous alundum cups were placed over the anodes to keep the corrosion products near the corroding surfaces, thus simulating conditions of the cables in the ducts. It was not possible to maintain the value of alternating current at one-half ampere because the porous cups became clogged and increased the cell resistance, therefore after about four months of operation the current was reduced to one-tenth ampere on all cells. The circuit used for these tests is shown in Figure 3.

Results of the tests, after continuous operation for eight months, are summarized in Table II.

These figures show that the combined rectified and galvanic currents of cell *A* caused the lead to lose approximately one fourth of its weight in eight months. The results on cells *B* and *C* indicate that the destruction of lead can be speeded up or practically stopped by superimposing direct current of the proper polarity. If the direct current is in the direction to make the lead anodic, corrosion is more rapid than when alternating current alone is applied. If the direction of the direct current is reversed and the lead made cathodic, corrosion ceases. In general, the tests showed that lead can be protected against even severe corrosive conditions by maintaining it cathodic with correctly applied direct current. Rectification tests indicated that about two per cent of the alternating current present at a new lead electrode is rectified, and to maintain the lead cathodic an amount of direct current slightly above this must be applied.

Rectification Study

The factors which affect rectification, and the characteristics of the phenomenon, were studied on eight lead–copper cells using four different samples of water for electrolyte which were obtained from widely separated sections of the Safe Harbor cable ducts. Duplicate cells were made with each type of electrolyte. The cells were continuously short-circuited except for a short period each day when they were energized with 25-cycle current for making observations of the rectifying action. With the circuit* shown in Figure 4 it was possible to measure fractions of a milliampere direct current in the presence of several amperes of alternating current. The transformer neutralized the alternating current in the measuring circuit, and the rectified current was measured on a microammeter shunted by one ohm.

Oscillograms of the alternating and direct currents were obtained by means of the bridge circuit shown in Figure 5. With a desired value of alternating current on a cell, the bridge was balanced by adjusting resistance R_1 until the galvanometer was at minimum deflection. The relatively high resistance of the two right arms of the bridge forced the rectified current through the oscillograph shunt R_3 and the left side of the bridge. Records obtained in this manner agreed with results obtained by the use of indicating instruments shown in Figure 4.

It was found that the rectifying action of the cells was a function of the surface of the lead electrode, and that rectification characteristics changed with the aging of the lead in the electrolyte, even to the extent of causing reversal of polarity of the rectified current. The curves of Figure 6 show the manner in which the age of the cell affected rectification for the eight cells used in the experiment. Direct current is plotted against increasing values of applied alternating current. The group of curves above the reference abscissa were obtained when the cells were new, with fresh electrolyte and cleaned and scraped electrodes. The lower group of curves are representative of the same cells three weeks later, with the cells having been short-circuited during the interval. All the curves show a small galvanic current in the absence of applied alternating current; under this condition lead is always anodic because of its position with respect to copper in the electromotive-force series of elements. When the cells were new, an increase in the amount of alternating current caused the lead to become increasingly anodic; but during the three-week period in which the cells were short-circuited, the rectifying characteristic of the lead underwent a change, after which the lead became increasingly cathodic with increased alternating current. This change is demonstrated in Figure 7. Here the curves show how polarity of the lead electrode changes from anodic to cathodic in the presence of alternating current as the cells age. It was found in these tests that the process of aging or forming of the lead to make it cathodic takes place more rapidly, and that the rectified current is of greater magnitude, in short-circuited cells than in cells continuously energized with alternating current.

Tests made with cells using water from the Holtwood cable ducts confirmed the

* Acknowledgment is made to E. F. Wolfe and Charles Wasserman of the Consolidated Gas Electric Light and Power Company of Baltimore for this circuit.

Table II

Cell	Applied Current	Weight of Lead in Grams		Per-Cent Change	Weight of Copper in Grams		Per-Cent Change
		Before	After		Before	After	
A	25 cycles only	119.7	90.2	−24.8	47.7	47.7	
B	Alternating plus direct—lead cathodic	116.8	116.3	− 0.4	48.8	20.0	−59.0
C	Alternating plus direct—lead anodic	112.8	52.5	−53.5	47.7	47.8	

earlier results at Safe Harbor that rectified currents in new cells are of the same polarity as the galvanic currents and add to the latter to make the lead increasingly anodic.

A number of experiments to determine the factors affecting rectification were carried out by varying the conditions under which the cells were tested. The conclusion was reached that rectification depends on the condition of the surface of the lead; polarity of the rectified current is dependent upon the pH of the electrolyte and the length of time the lead has been in the electrolyte. Newly cleaned and scraped electrodes placed in cells with fresh and with used electrolyte respectively indicate that age of the electrolyte does not affect rectification. However, when new clean lead electrodes

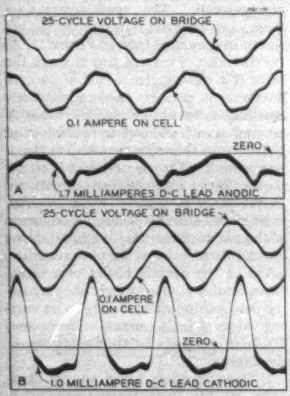

Figure 9. Rectification tests on lead–copper cells. Oscillograms showing wave form and polarity of rectified current on a new and an aged cell

A—Fresh electrolytic cell
pH is 8.2
Resistance is 630 ohms per cubic centimeter at 25 degrees centigrade
Cell age is 2½ minutes

B—Aged electrolytic cell
pH is 8.3
Resistance is 2,200 ohms per cubic centimeter at 25 degrees centigrade
Cell age is 2½ months

were substituted for aged ones, polarity changed from cathodic to anodic. Changing old copper electrodes for new ones made no difference in rectification. A ten-per-cent increase in rectified current resulted from an increase in temperature from 5 degrees to 50 degrees centigrade. Irrespective of whether the lead electrodes were tarnished, scraped, greased, oxidized, or rough surfaced, they were always anodic when first placed in a cell with a copper electrode and always became cathodic at a later time. Cells with two lead electrodes showed no rectification when the surfaces of the two were identical, but if one was new and the other cell-aged, as much as two per cent of the applied alternating current was rectified.

Inasmuch as the rectification apparently is due to the surface condition or film formation and the element of time, it is interesting to observe this effect in the field. A synchronized recording was made at Holtwood of the load current and the direct current in the ground connection of six cable sheaths in parallel. In Figure 8 the direct current is seen to be maximum at zero load current and in general decreases with an increase in load. The load swings produce corresponding changes in the direct current. However, a polarizing effect because of time is also present, particularly when the load current suddenly is reduced to zero or when suddenly applied.

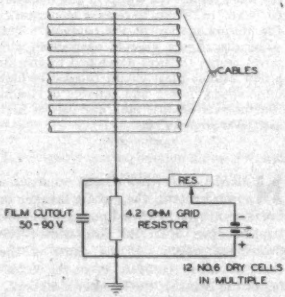

Figure 10. Method of applying counter potential for corrosion prevention

As a matter of general interest, the wave form and polarity of the rectified current in the laboratory cells is shown in the oscillograms of Figures 9A and 9B for a new cell and an aged cell.

Correlation of Laboratory Tests and Field Observations

As previously discussed, field observations made following the cable failures disclosed that load current affected the magnitude of direct currents flowing between sheaths and ground. On the replacement cable at Safe Harbor, the direct current increased from 2.7 milliamperes at no load to 12 milliamperes at full load. Because this cable was new the large increase of current correlates with the results obtained on new cells in the laboratory tests in which the rectified current was always in the same direction as the galvanic current, with the lead anodic. Referring again to Figure 2, the reversal of the direct current with load current above a certain value agrees with the characteristics found on aged cells, in which polarity of the direct current reverses to make the lead cathodic for alternating currents above given values. Since the rectified currents on aged lead oppose the galvanic currents and are in the direction to make lead cathodic, it might be expected that rectification would make the sheaths self-protecting above a critical load current, and this is no doubt true after the lead is sufficiently formed or aged. Since this process of forming is a function of several variable factors such as continuity and magnitude of load current, time, and quantity and character of water in the ducts, it is not possible to determine when the self-protecting condition will be attained. One method to provide definite protection to lead cables in wet ducts is the application of direct current in the direction to maintain the sheaths always cathodic.

Corrosion-Prevention Measures Applied to Cables

Inasmuch as the rectified currents in the field were, in some cases, in the direction to produce corrosion of the cable sheaths, and the galvanic currents always in this direction, the most obvious remedy was to apply a counter potential of a slightly higher order from an external source to force a flow of current in the opposite direction. The method adopted at Safe Harbor consisted of an application of a bank of 12 number 6 dry cells in multiple, connected across a resistor between the cable sheaths and ground bus as shown in Figure 10. Operating rules require that the sheaths must have a positive ground connection, and it was, therefore, not permissible simply to insert the batteries between sheaths and ground. The eight cable sheaths were connected together, then grounded through a 4.2-ohm grid resistor across which the batteries were operated. The resistor performs two functions. It provides a path to ground for any currents that might result from a cable-insulation failure, and in addition furnishes an IR drop which serves as the counter potential. It was found experimentally that a drop of one-half volt across the resistor made the sheaths cathodic to the duct and concrete at all points where they were accessible for observation. Since it was important that the sheaths be definitely cathodic at all points the ducts were chipped open at several places to make certain this condition existed.

Measures also were taken to provide drainage for the ducts at places where water had a tendency to accumulate, in order to keep the cables as dry as possible. Finally, an experimental installation of rubber-jacketed lead cable was made in the area where corrosion was most severe.

The possibility of increasing the resist-

ance of the cable sheaths to ground by flushing the ducts with clean water was investigated. The duct of one sheath section whose resistance to ground was 1.75 ohms was flushed continuously for seven days with the expectation that removal of the accumulated impurities would result in an improvement in resistance. After flushing, compressed air was blown through the duct for several weeks to dry it out. Results were disappointing; a slight decrease rather than an increase in resistance was effected, the final value being 0.9 ohm.

The failure at Safe Harbor occurred after the cables had been in service less than three years. The protective measures were applied immediately following the failure, and during the period of more than seven years which has elapsed since then no more failures have taken place.

The breakdown at the Holtwood plant occurred after the cable had been in service 12 years, indicating a much slower rate of corrosion. Corrosion-prevention measures taken here are similar to those employed at Safe Harbor, except that copper-oxide rectifiers instead of dry cells are used as a source of counter potential.

Conclusions

From the laboratory tests and field observations, it is reasonable to conclude that the cable failures described were the result of rectified induced alternating sheath currents in combination with galvanic currents, plus possibly a small amount of chemical action. The destructive effects of a-c corrosion were most pronounced when the cables were new and the ducts first became wet with alkaline seepage water. Evidence appears to indicate that the destructive effects of rectification decrease with time and eventually cease entirely as a result of a reversal of polarity.

It is important that in new installations of single-conductor lead cables in underground-duct systems caution be observed to guard against the effects of water seepage into the ducts. Galvanic currents may be expected to flow from the lead sheath to the usual metallic ground system, and when the ducts first become wet destructive effects also may be expected from the rectified induced sheath currents.

Data on laboratory cells showing how the rectification phenomena and corrosion change with respect to time cannot be used to predict changes in the field. They serve only to demonstrate the phenomena in a qualitative way. On short-circuited test cells, for instance, the rectified current reversed its polarity within several days after the cells were made; in contrast with this, on some of the cables in the field it was still in the anodic direction several years after the cables were installed.

New Solenoid Mechanism for Magne-Blast Breaker

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Synopsis: The existence of relatively high electromagnetic forces in circuit breakers when subjected to fault currents of appreciable magnitude has long been recognized. One of the problems in the design of a circuit-breaker operating mechanism is to provide smooth and effective closing performance, even though the breaker be closed against a short circuit and is thereby subjected to these high electromagnetic retarding forces during the final portion of the closing stroke. The greater the magnitude of the short-circuit current, the higher these electromagnetic retarding forces become and the more serious the effects of any tendency to "stall" or, worse, to reverse momentarily the closing motion of the contacts. This paper describes a solenoid mechanism with novel design features developed to operate a new Magne-Blast circuit breaker of high interrupting rating and capable of closing that breaker against fault currents as high as 80,000 amperes rms.

NORMALLY, when a fault occurs on a power system, the circuit breaker or breakers are in the closed position and are tripped open upon the response of the protective relays. If the cause of the short circuit is removed before the reclosing of the breaker, the breaker closes only the load current of the circuit. If, however, the cause of the short circuit is not removed before the reclosing of the breaker, the fault current is re-established as soon as the circuit-breaker contacts touch. This may occur frequently on systems which are reclosed automatically after fault operations, if the faults happen to be of a persistent nature. This re-establishment of short-circuit current by the touching of the circuit-breaker contacts sets up electromagnetic retarding forces, which, for the more simple contact arrangements, oppose the closing motion of the breaker. The magnitude of these opposing forces is proportional to the square of the short-circuit current, and in circuit breakers having high momentary and interrupting current ratings they may be very high. Any tendency of the circuit breaker to "stall" or reverse momentarily its closing motion at such high values of fault current easily might result in excessive contact burning or other undesirable disturbances in the breaker during the brief interval between establishment of the fault current and the subsequent tripping operation of the breaker.

The electromagnetic retarding forces responsible for this "stalling" action arise from the U-shaped loop circuit which is formed by the contacts and the conductor studs in most of the conventional contact arrangements. The more common of these conventional arrangements are shown in simplified form in Figure 1. As the direction of current flow through the blade is at right angles to that of the conductor studs, it exerts an electromagnetic repelling force on the blades which is greatest at each end and decreases toward the center as shown by the small distribution arrows. The magnitude of this retarding force for normal load currents can be measured in ounces, while on high short-circuit currents it may be measured in thousands of pounds. Figure 2 shows the calculated value of the peak retarding forces on the contact blades of a three-phase breaker having an eight-inch across-the-pole spacing when closing in on various values of fault current. The Appendix shows the basis for the calculation of these forces.

If these retarding forces are not overcome by the instantaneous-mechanism output force plus the forces from kinetic energy stored in the moving parts, "stalling" may occur. Figure 3A shows the contact stalling which occurs in an actual test breaker operated by a conventional solenoid mechanism when closing in against various values of short-circuit current. The stalling which occurred in

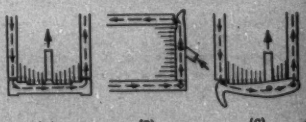

Figure 1. Contact arrangements on conventional small and intermediate ratings of circuit breakers

Dashed lines show U-shaped current path that produces the electromagnetic forces which are shown by the small arrows tending to open the contact blades

A. Oil circuit breaker
B. Low-voltage air circuit breaker
C. Magne-Blast power circuit breaker

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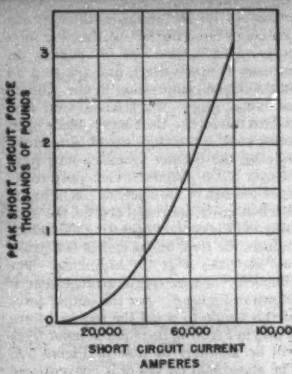


Figure 2. Peak magnetic retarding forces acting to retard closing motion of three-phase breaker closing against various short-circuit currents

these tests when closing currents of 60,000 amperes or above resulted in contact arcing and disturbance in the breaker. The duration of the stalling period increased with the short-circuit current, becoming as high as 12 cycles at 80,000 amperes. After stalling occurs, the solenoid current continues to build up as shown in Figure 3B and, when the solenoid output force finally exceeds the short-circuit retarding force, the breaker completes its closing stroke. Any advantageous utilization of kinetic energy has been lost.

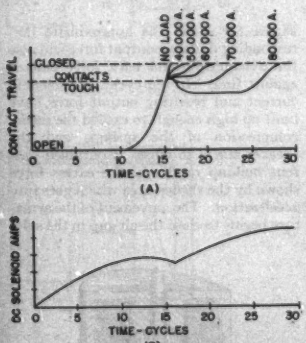


Figure 3. The effect of short-circuit magnitude upon stalling tendency during closing in conventional breaker

A. Conventional breaker closing travel versus time, closing against various values of short-circuit currents showing how stalling increases at contact making when breaker is closing higher short-circuit currents. After stalling breaker completes its closing stroke when solenoid builds up to a sufficiently high value to overcome retarding forces

B. Solenoid current buildup associated with A

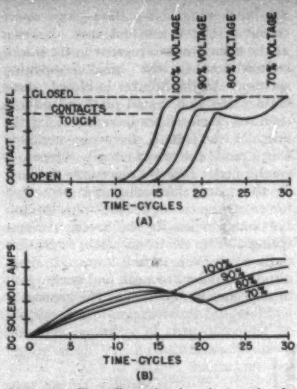


Figure 4. The effect of reduced control voltage upon stalling tendency during closing in conventional breaker

A. Conventional breaker travel-versus-time curves closing 50,000-ampere three-phase short circuit with various percentages of rated control voltage sustained at solenoid terminals, showing increased amounts of stalling which occurs with lower percentages of rated control voltage

B. Solenoid-current buildup curves for tests shown in A

This stalling tendency for conventional solenoid-mechanism designs is aggravated greatly if we reduce the d-c control voltage maintained at the solenoid terminals. Figure 4A shows the amount of stalling obtained when closing against a 50,000-ampere short circuit with various percentages of rated control voltage maintained at the coil terminals. The progressively lower d-c solenoid-current buildup rate for each of these voltages is shown in Figure 4B and results in

1. Longer time delay before starting to close.
2. Lower closing speed.
3. Increased stalling at contact making.

In recognition of these effects, recommended practice requires at least 90-percent rated control voltage to be maintained at the coil terminals of any breaker that may be required to close in against a short circuit. As further insurance against the effects of possible stalling, application recommendations for some time have required instantaneous tripping relays, which are operative only during the breaker closing operation, to be included as part of the essential equipment in all locations where the short-circuit

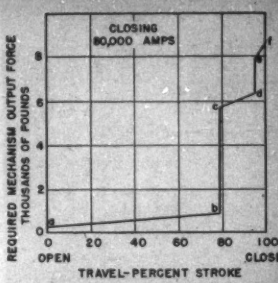


Figure 5. Variation of force at breaker contacts throughout closing stroke

0-*a* = initial compression in breaker opening springs

a-b = the increase in force as these springs are compressed

b-c = peak electromagnetic retarding forces of short circuit plus initial compression in arcing-contact springs

c-d = increase in arcing-contact-spring pressure as these springs are compressed

d-e = initial compression in primary-contact springs

e-f = increase in primary-contact-spring pressure as these springs are compressed

current may exceed a stipulated value. As these relays are operative only when the closing control circuit is energized, they do not interfere with the selective relays used to trip the breaker from its normally closed position. These relays limit the duration of any possible "stalling" to a value of the order of two to four cycles. However, it has been realized that it is highly desirable, in new designs, to eliminate completely stalling over the entire operating range of control voltage. Accordingly, an improved mechanism design with greater instantaneous output force has been developed.

This mechanism design, applied to a 500,000-kva Magne-Blast breaker has demonstrated the ability to close and latch that breaker, without stalling, against three-phase short-circuit currents in excess of 80,000 amperes rms, that is, in excess of the momentary current rating of the breaker. Any adverse effects of "stalling" such as sustained contact arcing or other disturbances in the breaker thus are eliminated, and the provision of the instantaneous overcurrent tripping relays previously referred to is no longer required.

The remainder of this paper describes the development and construction of new solenoid mechanisms of this design, which employ a flux-shifting principle of operation.

Analysis of Problem

In the development of a mechanism to eliminate stalling when closing against

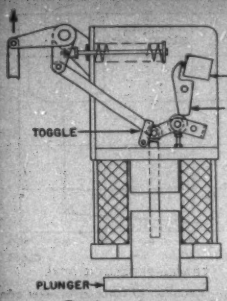


Figure 6. Toggle mechanism used to reduce required solenoid force at closed position on Magne-Blast breaker showing simplicity of linkage

high short circuits, it is necessary first to analyze the forces involved. Figure 5 shows how the breaker closing forces vary through the stroke. Curve *a-b-c-d-e-f* represents the closing-force curve which the mechanism must supply when closing the breaker against a three-phase short circuit of 80,000 amperes rms. Point *a* at the open position represents the initial compression in the breaker opening springs. As the breaker is closed, these springs are compressed further, and the required closing force increases along the line *a-b*. At point *b*, the arcing contacts touch and the short-circuit current is established. Line *b-c* represents the sum of the peak electromagnetic retarding forces on the contact blades plus the initial compression in the arcing contact springs. The electromagnetic forces initially are cyclic in nature, varying in magnitude from zero to peak and back again to zero once per cycle. As the breaker is closed on in, the arcing contact springs are compressed further, so that the force increases along line *c-d*. At point *d* the primary contacts meet, and the step *d-e* is the initial compression in the primary contact springs. If a solenoid were connected directly to the contact-blade operating rods, it therefore would be required to close the breaker against a final force of over 8,000 pounds. Generally to reduce the size of the solenoid coil, a toggle mechanism is inserted between the solenoid and the contact operating rods which reduces the force at the end of the stroke and increases it at the beginning. The simplicity of this toggle arrangement is shown in Figure 6. For the output force of this toggle to equal the required force shown in Figure 5, its required input force will be modified to that of Figure 7A. The static pull curves of a conventional solenoid capable of producing sufficient output force to close this breaker are shown in Figure 7B. Although this conventional solenoid ultimately will close the breaker against 80,000 amperes, it will result in serious stalling at the time contacts meet as the coil current will not yet have built up to a high enough value to exceed point *c* and close the breaker. This can be seen from Figures 8A, 8B, and 8C. Figure 8A shows the d-c solenoid-coil-current buildup versus time which, when eddy currents are neglected, follows the equation:

$$E = Ri + \frac{d(Li)}{dt} = Ri + L\frac{di}{dt} + \frac{dL}{dt}$$

Figure 8B shows the approximate corresponding dynamic output force and also the dynamic breaker back force plotted against time. In ten cycles the solenoid current and resulting output force have built up high enough to exceed the initial compression of the springs, and the breaker starts to close. Continued current buildup results in the excess force shown by the shaded area which goes into acceleration. The movement of the armature begins to close the air gap in the sole-

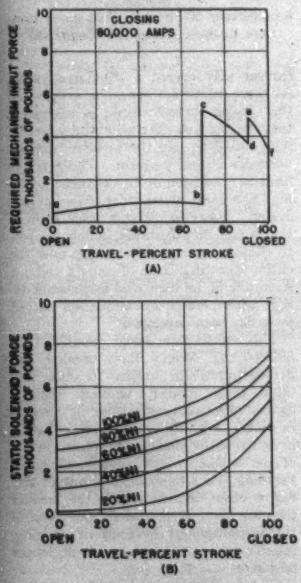


Figure 7. Mechanism input forces as modified by toggle linkage

A. Input force to mechanism in Figure 6 to equal output force required in Figure 5 at breaker contacts with magnetic force included

B. Static-pull curves of conventional solenoid capable of producing output forces required in Figure 7A to close breaker at 70-per-cent rated current

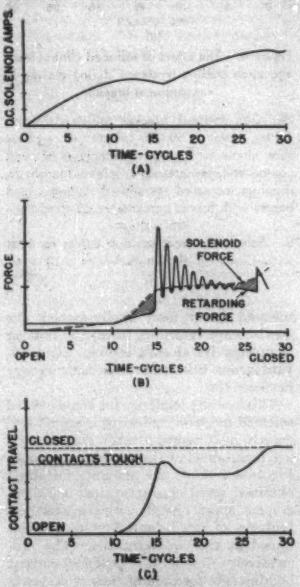


Figure 8. Conventional solenoid-current buildup, dynamic output force, and stalling when closing 80,000-ampere short circuit

A. D-c solenoid-current buildup versus time with closing operation for breaker with conventional solenoid mechanism when closing against 80,000-ampere three-phase short circuit

B. Dynamic-solenoid-output-force buildup versus time associated with solenoid-current buildup shown in A plotted over required static-force curve to close breaker. Shaded area equals excess of solenoid output force which goes into accelerating breaker contacts

C. Closing travel versus time resulting for breaker closing against 80,000-ampere three-phase short circuit showing stalling due to short-circuit magnetic forces at time of contact touching

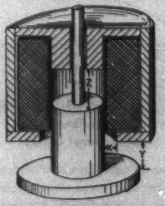


Figure 9. Improved flux-shifting closing solenoid-coil design with bottom plate on plunger

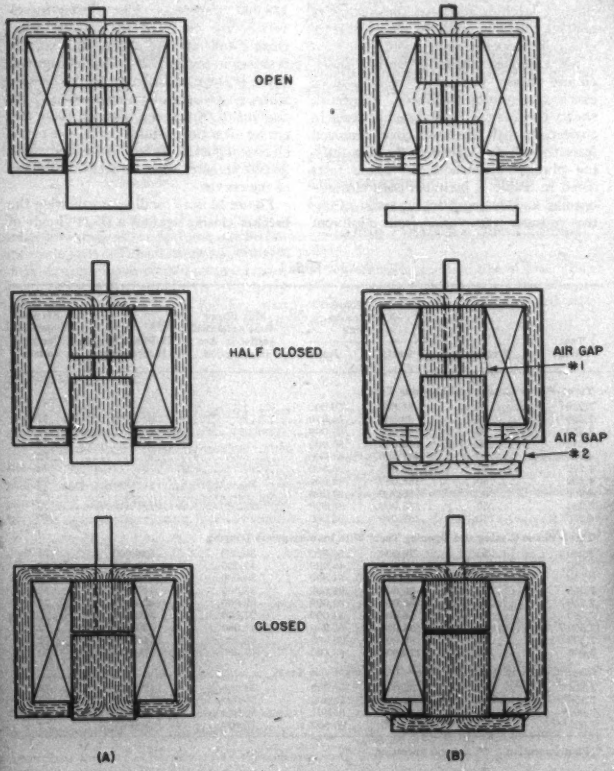
X = air gap around circumference of plunger
Y = air gap to bottom plate which short-circuits gap *X* as plunger closes
Z = normal air gap at top of plunger

uoid, which tends to increase the inductance of the coil. This increasing inductance generates a back electromotive force, $[i(dL/dt)]$ which decreases the rate of current buildup, or even momentarily may cut the current down. Figure 8C shows the associated breaker-contact travel. In 15 cycles the contacts touch, though the solenoid output force has not yet built up to the required short circuit plus contact force, and so the breaker stalls until the solenoid current builds up high enough to exceed these forces and complete the closing stroke.

The stalling with the conventional solenoid can be reduced somewhat by increasing the amount of toggle which raises the required force at the open position but decreases it faster as the stroke progresses. This action holds the breaker back until the coil current has built up to a higher value before it can start closing. There is a limit, however, to this hold-back action, as it results in a higher excess force all the way through the stroke, and this greatly increases acceleration and speed so that abnormal dashpots or closing buffers may be required to absorb the impact of closing this breaker against no load. Excessive closing speeds are to be avoided if possible to increase the mechanical life of the breaker. An extremely long maintenance-free operating life is a prerequisite on Magne-Blast breakers, as many of them are used on highly repetitive industrial applications where 15,000 to 30,000 operations per year are not unusual.

Figure 10. Flux paths for various positions in *A* the conventional solenoid, and *B* the double-air-gap solenoid

In the open position, the flux path in the two types of solenoids is the same, but, as the plunger nears the closed position, more and more of the flux in the double-air-gap solenoid is shifted from the nonpulling annular gap to the pulling gap of the bottom plate, as shown in the half-closed and closed positions



Improved Solenoid Design

To avoid high closing speed and still close against high currents without stalling, the solenoid mechanism should provide a normal dynamic output pull in the early part of its stroke of about the same magnitude as the conventional solenoid. When the contacts meet, however, the output force should rise rapidly without delay to pull the breaker contacts closed without waiting for the coil current to increase in value. The total pull from a conventional solenoid plunger depends on the total flux across the pulling gap into the plunger. It is impossible to increase quickly the total amount of flux in the magnetic circuit on account of the inductance of its path, but it is possible to

Figure 11. Rear of Magne-Blast breaker with arc chutes removed and tension springs connected through lost-motion linkage to operating rod shaft simulating short-circuit retarding forces

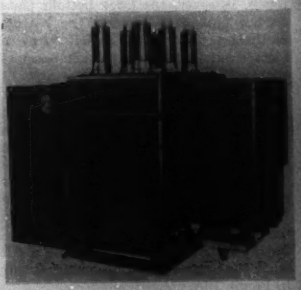


Figure 12. A 500,000-kva Magne-Blast circuit breaker with lower cover removed from solenoid to show flux-shifting plunger construction

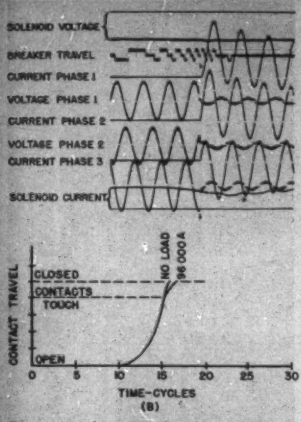


Figure 13. Improved flux-shifting solenoid closing against 96,000-ampere three-phase short circuit

A. Oscillogram showing breaker closing and latching on 96,000-ampere rms three-phase short circuit with 70-per-cent rated control voltage sustained at solenoid terminals

B. Flux-shifting-solenoid closing-travel-versus-time curve when closing and latching against no load and when closing and latching against 96,000 amperes as determined from the oscillogram in A

shift its path so that the same flux crosses two pulling gaps.

Figure 9 shows a plunger solenoid design in which the initial flux path in the open position is across the annular gap X up through the cylindrical plunger and through the pulling gap Z to the pole piece and down through the return circuit. The plunger, however, is fitted with the large bottom plate B. In the early part of the stroke practically all the flux flows across gap X. As the plunger closes in to the point where the breaker contacts touch, however, the large bottom plate on the plunger approaches the bottom of the magnetic return circuit so as to form a new gap at Y, which becomes shorter than gap X. The major amount of the flux therefore will have shifted by this time from the nonuseful gap X to the additional pulling gap Y which adds its force to that of Z. With no increase in total flux, therefore, this flux-shifting design exerts a greater pulling force at the end of the stroke. Figure 10B shows how this flux path shifts for various positions during the stroke for a solenoid with the modified magnetic circuit as compared with the conventional magnetic circuit in Figure 10A.

The original development tests on this double air-gap type of solenoid were made by simulating the short-circuit forces with heavy tension springs fastened through a partial-stroke lost-motion connection to the mechanism output shaft. Figure 11 is the rear view of a breaker resting on a framework with arc chutes removed to show these tension springs. A Cincinnati analyzer is mounted on top of the breaker to measure contact travel. By varying the tension in these springs, it is possible to simulate various magnitudes of short-circuit currents. Dynamic flux measurements made during these tests determine the optimum air gap and bottom-plate dimensions for the solenoid magnetic circuit.

The conventional solenoid plunger construction first tested in this manner was shown to be capable of closing against a spring load equivalent to a 50,000-ampere three-phase short circuit with 90-per-cent control voltage. In contrast, the modified flux-shifting solenoid using the same coil-and-mechanism toggle construction closed successfully against a spring load equivalent to 95,000 amperes without stalling even when the control voltage was reduced to approximately 70 per cent of rated voltage. This represented an increase of over 1,800 pounds (peak oscillating force of 3,600 pounds) in plunger latching force, at the instant of contact touching, with no appreciable increase in breaker closing speed.

An extended series of actual short-circuit closing tests was then made to check the results obtained. Figure 12 shows the Magne-Blast breaker used in these tests with the lower cover removed from the solenoid to show the flux-shifting plunger construction. These tests listed in Table I, included both closing–opening and closing–latching tests. Control voltages were varied from minimum to 100-per-cent normal and the short-circuit current exceeded 80,000 amperes rms in a number of tests. No stalling occurred on any tests, and there was no disturbance at the breaker. The positive no-stalling closing action reduced contact erosion to a negligible amount.

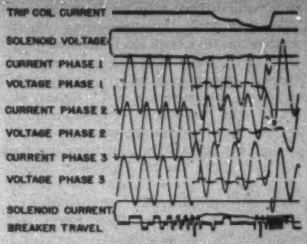


Figure 14. Oscillogram showing breaker closing against 75,000 amperes tripped instantly, interrupting 540,000 kva at 7,250 volts

Figure 13A is an oscillogram showing the breaker closing and latching against 96,000 amperes rms (peak current = 158,000 amperes). The closing-travel-versus-time curve of the breaker when closing and latching against this current is shown in Figure 13B. Plotted over this curve is the closing curve of the breaker when closed against no load. The slight amount of divergence between these two curves after the contacts touch, due to the electromagnetic forces associated with 96,000 amperes, can be seen at the top of the curves.

Figure 14 is an oscillogram showing the breaker closing against a short circuit of

Table I

Test Voltage	Frequency	Max Phase Amperes on Closing: Peak	Max Phase Amperes on Closing: Rms	Max Phase Rms Amperes Initial in Arc Interruption	3-Phase Kva Interruption	Per-Cent Normal Solenoid Control Voltage
Three-Phase Closing and Latching Tests						
7,250	60	84,000	50,000			72
7,250	60	90,000	54,000			72
7,250	60	92,000	53,000			72
7,250	60	112,000	66,000			72
4,200	60	147,000	87,000			72
4,200	60	158,000	95,000			72
4,200	60	155,000	92,000			95
4,200	60	158,000	94,000			95
4,200	60	148,000	88,000			80
4,200	60	158,000	96,000			80
Three-Phase Closing and Opening Tests With Instantaneous Tripping						
7,250	30	76,000	50,000	30,000	380,000	72
7,250	30	75,000	45,000	31,000	390,000	72
7,250	30	57,000	34,000	34,000	430,000	72
7,250	30	59,000	35,000	35,000	440,000	72
7,250	30	66,000	39,000	39,000	490,000	72
7,500	60	56,000	34,000	24,000	310,000	72
7,500	60	92,000	55,000	41,000	530,000	72
7,250	60	99,000	60,000	43,000	540,000	72
7,000	60	120,000	73,000	47,000	570,000	72
Close–Open + 15 Seconds + Close–Open Duty-Cycle Test						
7,250*	60	92,000	56,000	33,000	420,000	72
7,250**	60	89,000	53,000	35,000	440,000	72
7,000*	60	100,000	59,000	39,000	470,000	72
7,000**	60	120,000	70,000	45,000	550,000	72

* First operation. ** Second operation.

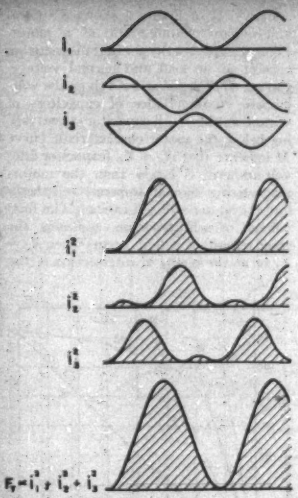


Figure 15

i_1, i_2, and i_3 are the three-phase short-circuit currents when closing 100-per-cent inductive circuit

i_1^2, i_2^2, and i_3^2 are the squares of these currents which are proportional to magnetic retarding forces on individual switch blades

$F_T = i_1^2 + i_2^2 + i_3^2$ is the total three-phase magnetic retarding force for the three phases of breaker

73,000 amperes rms (120,000 amperes peak) followed by a tripping operation one cycle later. The short-circuit current at interruption was 47,000 amperes rms, which represented 570,000 kva. The total interrupting time of the breaker was three cycles from trip impulse to interruption.

Conclusions

The double-air-gap flux-shifting solenoid mechanism designed for operating the Magne-Blast breaker makes this breaker equally adaptable to public-utility and industrial applications. It provides a mechanism for reclosing that breaker against maximum fault currents

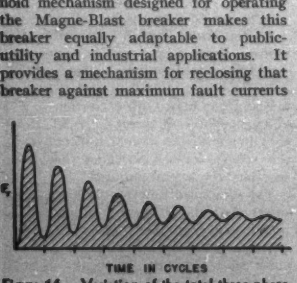


Figure 16. Variation of the total three-phase magnetic retarding force (Ft) with respect to time

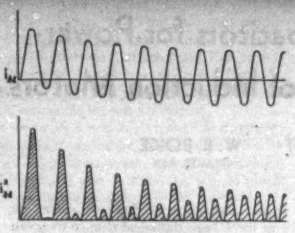


Figure 17

i_{s-l} is the single-phase fault current when switch is closed at zero voltage point on voltage wave

i_{s-l}^2 is the square of single-phase fault current which is proportional to magnetic retarding force on blade

with minimum control voltage maintained at the coil terminals, without stalling and without damage to the contacts. For industrial applications it provides a positive mechanism of extremely simple design and few moving parts with an operating speed fitting it for highly repetitive applications such as steel-mill motor control and arc-furnace control, without requiring excessive adjustment or replacement of parts.

Appendix. Calculation of Electromagnetic Forces on Circuit-Breaker Contacts When Closing Against a Short Circuit

The transient current which flows upon the closing of a switch in an inductive circuit with a sinusoidally varying impressed voltage is given by the equation:

$$i = \frac{E_m}{\sqrt{R^2+(\omega L)^2}} [\sin(\omega t+\theta-\phi) - \epsilon^{-\frac{Rt}{L}} \sin(\theta-\phi)] \quad (1)$$

where

θ = electrical angle from zero voltage to making of circuit

ϕ = angle of lag of current behind voltage or power-factor angle $\left[\text{equal to } \tan^{-1}\left(\frac{\omega L}{R}\right)\right]$

If we neglect resistance in the circuit, $R=0$, and $\phi=90$ degrees, and the equation becomes

$$i = \frac{E_m}{\omega L} [\sin(\omega t+\theta-90°) - \sin(\theta-90°)] \quad (2)$$

Closing a three-phase switch upon a three-phase a-c short circuit similarly gives rise to three currents equal to

$$i_1 = \frac{E_m}{\omega L} [\sin(\omega t+\theta-90°) - \sin(\theta-90°)] \quad (3)$$

$$i_2 = \frac{E_m}{\omega L} [\sin(\omega t+\theta-90°-120°) - \sin(\theta-90°-120°)] \quad (4)$$

$$i_3 = \frac{E_m}{\omega L} [\sin(\omega t+\theta-90°-240°) - \sin(\theta-90°-240°)] \quad (5)$$

θ being measured in all cases from the instantaneous voltage zero in the first phase.

If these switch blades bridge at right angles two parallel conductors as shown in Figure 1 of the paper, the instantaneous magnetic force tending to open each switch blade is equal to

$$F = 4.5 i^2 K \ 10^{-8} \text{ pounds}^* \quad (6)$$

where

i = the current in that blade

K = a constant determined by switch proportions

$$= \log_e \frac{S}{0.779R} \frac{l+\sqrt{l^2+R^2}}{l+\sqrt{l^2+S^2}}$$

S = distance between parallel conductor centers—inches

R = radius of parallel conductors—inches

l = length of parallel conductors—inches

The total instantaneous magnetic force then acting upon the three switch blades is equal to

$$F_t = 4.5(i_1^2+i_2^2+i_3^2)K \ 10^{-8} \text{ pounds} \quad (7)$$

When i_1, i_2, and i_3 are squared and added together, it will be found that all the terms involving the closing angle θ cancel out, and

$$i_1^2+i_2^2+i_3^2 = \frac{E_m^2}{(\omega L)^2} 3(1-\cos \omega t) \quad (8)$$

The sum of the squares of the three instantaneous currents therefore are independent of the closing angle θ.

The total instantaneous magnetic retarding forces on the blades of a switch closing on a zero-power-factor three-phase short circuit are equal to

$$F_t = 4.5 \left(\frac{E_m}{\omega L}\right)^2 3(1-\cos \omega t) K \ 10^{-8} \text{ pounds} \quad (9)$$

This force starts at zero and reaches a crest of $\frac{27(E_m)^2}{(\omega L)^2} K \ 10^{-8}$ in 180 degrees and drops to zero again in 360 degrees as shown in Figure 15. If the circuit contained zero resistance, this force would continue to oscillate indefinitely, as all three of the phase currents each would retain its original amount of displacement. Because of the resistance in any actual circuit, however, these currents eventually will become symmetrical, after which the sum of the magnetic forces has a constant value one-fourth its original peak magnitude as shown in Figure 16.

As previously shown the total of the three magnetic retarding forces for a three-phase

*This equation is based upon the switch blades being spaced far enough apart so that each blade is not acted upon by the currents in the other two phase parallel conductors. It does not hold with very close phase spacings.

Application of Capacitors for Power-Factor Improvement of Induction Motors

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POWER-FACTOR improvement of induction-motor loads by means of shunt capacitors has been a common practice for many years. Recently, the practice of connecting the capacitors directly at the motor terminals has developed in order to permit switching of the capacitors and motor as a unit. This will not result in adverse motor operation if the number of capacitors is selected properly. There is very little written material regarding operating experience, although capacitor and motor manufacturers have accumulated some experience.[1,2,3,4] This experience has shown that frequently too large a capacitor rating was used, resulting in overvoltage due to self-excitation when the motor starter was opened; in some cases the voltage rose to 200 per cent causing failure of motor insulation, indicating lamps, and other devices. In several instances, the motor coupling and shaft were damaged when too large a capacitor bank was used and the motor switched by a reduced-voltage autotransformer-type starter. In some cases, motors have been damaged from overload because allowance was not made in the overload setting for the reduction in line current due to the capacitors. In other cases, instruments and meters connected in the current-transformer secondary circuit have been damaged due to overvoltage.[5]

The purpose of this paper is to discuss these problems and their solution. A useful application table is included which lists the maximum capacitor rating for use with motors and the reduction in line current with the recommended capacitor rating. This latter information is useful for selecting the proper overload-relay setting.

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Overvoltage Due to Self-Excitation

Self-excitation refers to the action of an induction motor operating as an induction generator with excitation supplied by capacitors, such as may occur when the switch is opened and the running motor is disconnected from the power source or when the motor is driven by an external means.

The mathematical theory of self-excitation is involved[6] and here only a simplified graphical solution will be given. If resistance is neglected, self-excitation will occur when

$$X_C \leqq X_L$$

X_C = capacitive reactance

X_L = magnetizing reactance

(A small value of X_C corresponds to a large capacitor kilovolt-ampere rating.) For practical purposes $X_C = X_L$ when the capacitor kilovolt-ampere rating is equal to the magnetizing kilovolt-ampere of the motor. This is very nearly the reactive kilovolt-amperes or kilovars at no load.

Curve *M* of Figure 1 shows a typical volt-ampere characteristic of a motor. Point *A* indicates the per cent magnetizing current at no load and normal voltage. Curves *C1*, *C2*, *C3*, and *C4* show the volt-ampere characteristics of capacitors of various ratings. All capacitor curves falling below the motor-characteristic curve *M* indicate that $X_C < X_L$ (capacitor kilovolt-amperes is larger than the motor-magnetizing kilovolt-amperes) and therefore the motor will self-excite. The final voltage of self-excitation, assuming the speed remains constant, occurs when $X_C = X_L$ or at the points of intersection of the

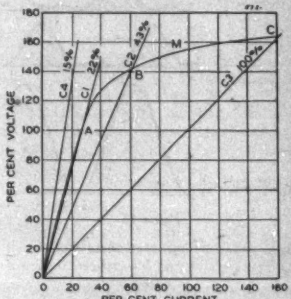

Figure 1. Motor-excitation curve and capacitor volt-ampere characteristic curves

capacitor curve with the motor-characteristic curve (points *A*, *B*, and *C*). Capacitor curves above the motor curve, such as curve *C4*, indicate that the capacitor kilovolt-amperes is less than the motor-magnetizing requirements, and the motor will not self-excite. Self-excitation can be checked by connecting a voltmeter across the motor terminals and reading the voltage after the switch is opened.

Curve *C2* of Figure 1 is for the case where the capacitor kilovolt-amperes is sufficient to improve the motor full-load power factor to 100 per cent. Note that the voltage of self-excitation is 143 per cent; this will vary among motors and may be considerably higher for some.

In the usual motor application, the motor slows down rapidly after the switch is opened and the voltage rapidly decreases; a 15- to 20-per-cent reduction in speed eliminates self-excitation so the voltage collapses in a few seconds. However, in a few cases with high-inertia loads the voltage of self-excitation has been sustained for several minutes.

The graphical solution described assumes that the frequency of self-excitation is equal to the power-system frequency. This is approximately true in most cases since the frequency of self-excitation corresponds to the motor speed which is very nearly synchronous speed.

Overvoltage may be reduced by means

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short circuit is independent of the closing angle of the circuit. For a single-phase fault current, however, the crest value of these forces will vary 4 to 1, and their average over a cycle will vary 3 to 1 depending upon the closing angle of the circuit. The highest value is obtained when a line-to-line fault occurs beyond the breaker at a zero point on the voltage wave. In this case, a full-offset current wave flows through two poles of the breaker simultaneously.

$$i_{l-l} = \frac{E_{m\,l\,to\,l}}{2\sqrt{R^2+(\omega L)^2}} [\sin(\omega t+\theta-\phi) - \epsilon^{-\frac{R}{L}t}\sin(\theta-\phi)] \quad (10)$$

where

$E_{m\,l\,to\,l}$ = line-to-line voltage = $1.73E_m$

If we neglect resistance and close at 0 degrees to this line voltage,

$$i_{l-l} = \frac{1.73E_m(1-\cos\omega t)}{2\omega L} \quad (11)$$

The magnetic retarding force associated with this current is equal to

$$F_{ll-l} = 4.5K\frac{3E_m^2(1-\cos\omega t)^2}{4(\omega L)^2}10^{-8} \quad (12)$$

The peak of this force is equal to that for the three-phase fault condition in equation 9.

As this short-circuit current becomes symmetrical, this force dies down to a double-frequency oscillating force as shown in Figure 17. If the switch had been closed at peak voltage, the current would have been symmetrical in the first loop, and the forces would have started out at their final value.

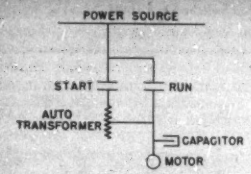


Figure 2. Diagram of reduced-voltage autotransformer-type motor starter

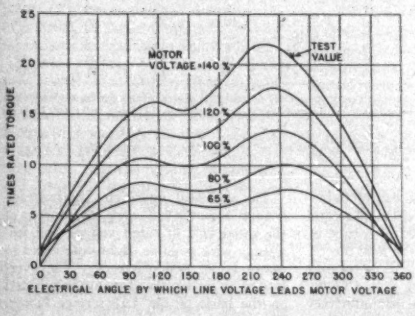


Figure 3. Peak electrical torque versus switching angle

of a series or shunt resistance in the capacitor circuit but generally such devices are not used because of the continuous losses or the complication of switching the resistor to avoid the losses.

Overvoltage alone may not be the sole criterion for selecting the amount of capacitors to use; the listings of Table I consider both transient torque and voltage.

Transient Torques

When a running induction motor with shunt capacitors is connected to a power source, a high transient torque may be developed. This may occur when a motor is transferred to the line from the reduced-voltage tap of an autotransformer-type starter, Figure 2. This also may occur when a running motor temporarily is disconnected from its line, and the switch (Figure 5) is reclosed while the motor is still running and maintaining voltage at its terminals by self-excitation.

In order for transient electrical torques to appear, the motor voltage developed by self-excitation must be of appreciable magnitude and it must be out of phase with the line voltage when the switch is closed. The torque is similar to that caused by connecting two synchronous generators together which are out of phase.

If there is no load connected to the motor shaft, the torque will be absorbed by the motor inertia and will result merely in a momentary acceleration or deceleration of the motor, lasting for a few cycles.

If the inertia of the load connected to the shaft is appreciable, some of the torque will be transmitted by the shaft to cause acceleration or deceleration of the load. If the load inertia is several times the inertia of the motor rotor, most of the transient electrical torque will be transmitted as transient mechanical torque by the shaft and coupling. In some cases this has caused fracture of couplings and twisting of shafts.

The peak value of the electrical torque is determined primarily by the magnitudes of the line and motor voltage, the electrical angle between them, and the reactance and resistance of the motor. High transient torques are accompanied by high transient line currents. The transient torque is of an oscillating character, lasting only for a few cycles and usually having its maximum value in a decelerating direction. The values of peak torque obtainable for a typical motor are shown by Figure 3.

A series of tests was made to verify the expected values of transient torque. Figure 4 is an oscillogram of a test made on a 100-horsepower motor with 40 kva of capacitors connected to its terminals. This amount of capacitors improved the full-load motor power factor to substantially 100 per cent. The motor and capacitor bank were switched as a unit from reduced voltage to full voltage by means of a manual reduced-voltage autotransformer-type starter. No load (except a tachometer) was connected to the motor shaft. The maximum torque developed

Figure 4. Oscillogram of test for transient torque of induction motor with shunt capacitors

Motor rating: 100 horsepower, 1,800 rpm, 2,200 volts, 24 amperes. Capacitor rating: 40 kva

Motor started with manual reduced-voltage autotransformer starter. No load connected to motor shaft

Maximum electrical torque (from slope of speed trace and motor inertia) = 21 times motor rated torque

Tachometer deceleration trace not used, since peak went off film. This trace obtained from oscillograph element in series with capacitor across tachometer. Harmonics in this trace are due to commutator ripple and slight misalignment in tachometer coupling

Line-voltage trace obtained from special circuit which shows only the peaks of the voltage wave

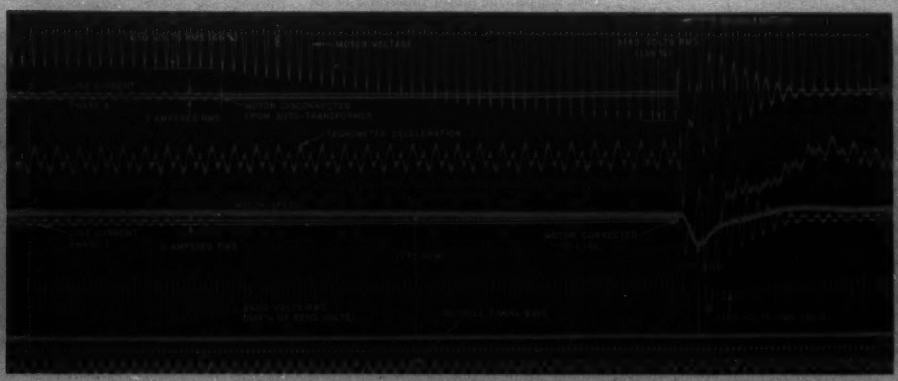


Table I. Recommended Maximum Capacitor Rating When Capacitor and Motor Are Switched as a Unit*

Representative Data for Three-Phase 60-Cycle General-Purpose Open-Type Induction Motors of 220-, 440-, 550-, and 2,300-Volt Rating

Induction-Motor Horsepower Rating	Motor Speed in Rpm											
	3,600		1,800		1,200		900		720		600	
	Ckva**	%AR‡	Ckva	%AR	Ckva	%AR	Ckva	%AR	Ckva	%AR	Ckva	%AR
10	2.5	9	4	11	4	12	5	17	5	23	7.5	28
15	2.5	9	5	11	5	11	7.5	16	7.5	21	10	26
20	5	9	5	10	5	11	7.5	15	10	20	12.5	24
25	5	9	7.5	10	7.5	10	10	14	10	19	15	22
30	7.5	9	10	9	10	10	10	13	12.5	18	15	21
40	10	9	10	9	10	10	12.5	12	15	16	17.5	19
50	12.5	9	12.5	9	12.5	9	15	12	20	15	22.5	17
60	15	9	15	8	15	9	17.5	11	22.5	14	25	16
75	17.5	9	17.5	8	17.5	8	20	11	27.5	13	30	15
100	22.5	9	22.5	8	22.5	8	25	10	35	12	37.5	14
125	25	9	27.5	8	27.5	8	30	9	40	11	47.5	13
150	32.5	9	35	8	35	8	37.5	9	47.5	11	55	13
200	42.5	9	42.5	8	42.5	8	45	9	60	10	67.5	12

* When manual reduced-voltage autotransformer-type starter such as shown in Figure 2 is used, refer to method described in the text for selecting the capacitor rating if load data is appreciably higher than that of the motor. The motor full-load power factor, with capacitor ratings as listed in this table, will range from 95 to 98 per cent.

** CKVA is rated kilovolt-amperes of capacitors connected at motor terminals.

‡ %AR is per cent reduction in line current due to capacitors and is helpful for selecting the proper motor-overload setting when the overload relay is located as shown in Figure 5.

was determined from measurement of the maximum rate of change of motor speed and a calculated value of motor inertia. In the case shown by Figures 3 and 4, there was a delay of approximately 0.7 second from the time the motor was disconnected from the 65-per-cent autotransformer tap until it was connected to the line. During this interval, the motor voltage built up to 138 per cent by self-excitation and became about 252 degrees out of phase. The resulting high torque is apparent from the rapid momentary deceleration of the motor after transfer to the line. The measured torque was 21 times rated torque. This measured value is plotted on Figure 3, from which the good agreement between calculated and test results can be seen.

In order to prevent transient mechanical torques from damaging the shaft and coupling, the peak mechanical torque should not be permitted to exceed about six times normal. In general, if the connected capacitor kilovolt-amperes does not exceed the value given by Table I, excessive torques will not result from switching occasioned by the use of electrically operated reduced-voltage starters. This is true because the switching time is so short that a high motor voltage and electrical angular difference does not appear.

If manual switching is employed, and the load inertia is appreciably higher than that of the motor, excessive shaft torques may develop. It is suggested that such cases be given special consideration, taking the particular motor characteristics and load inertia into account before selecting a value of capacitor kilovolt-amperes to be connected to the motor terminals to be switched with the motor. This may be done as follows: By the graphical method outlined in this paper, the maximum motor voltage from self-excitation by a trial selection of capacitors can be determined. From Figure 3 for this motor voltage, the maximum electrical torque can be determined. The maximum mechanical torque will be less than the electrical torque in the same proportion that the load inertia is less than the total inertia of motor and load. The capacitor rating should be selected by trial such that the maximum mechanical torque in the shaft and coupling, determined in this manner, does not exceed six times normal. As previously indicated, this procedure is not necessary if the switching time is less than about 0.3 second, as would be the case for most electrically operated motor starters.

Thermal-Overload Protection of the Motor

When capacitors are connected to the motor terminals they supply some of the motor-magnetizing requirements so the actual line current is less than it would be without capacitors. If the capacitors are connected to the motor starter on the load side of the thermal-overload device as shown in Figure 5, the overload relay will not provide proper protection to the motor if it is selected for the uncorrected motor full-load current. The relay should be selected for a smaller current rating commensurate with the reduced line current due to the effect of the capacitors.

The per cent reduction in line current due to capacitors is shown in Table I. Note the large reduction in line current for the slow-speed motors.

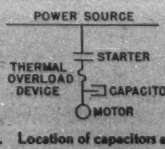


Figure 5. Location of capacitors and thermal-overload relay

The standard open-type squirrel-cage induction motor will carry 115 per cent of the rated load at rated voltage and frequency with possible slight differences in power factor and efficiency. The overload-relay setting therefore can be selected on the basis of the 1.15 service factor. The reduction in current as listed in Table I applies for either the 100- or 115-per-cent loading. Examination of data for motors of various horsepower and speed ratings has shown this to be true.

Overvoltage Protection for Current-Transformer Secondary Windings

Excessive overvoltages (several thousand volts) have been observed in current-transformer secondary circuits of motor circuits with shunt capacitors for rotating-machine protection or power-factor improvement. The analysis of this was described in a recent paper.[5]

Referring to Figure 6, when a de-energized capacitor is switched on to the bus it appears initially as a short circuit since the capacitor voltage cannot be changed instantaneously. Therefore, the instant the switch is closed the system voltage is distributed in the impedance from the bus to the capacitor, and since the impedance of the current transformer may constitute a major portion of this circuit impedance, it may assume the major part of the voltage drop. The voltage as viewed from the transformer secondary winding will be increased by the turn ratio. The magnitude of this voltage also will depend upon the volt-ampere burden in the transformer secondary circuit; the larger the burden in volt-amperes the higher the voltage. The amount of capacitors at the motor terminals has very little effect on the magnitude of the voltage.

Many types of protective devices can be used in the current-transformer secondary circuit, such as a shunting resistor,

cutout, or filter. Very effective protection is provided by a by-pass device of a ceramic material having a nonlinear-resistance characteristic designed to shunt the current-transformer secondary terminals and thus limit the magnitude of the overvoltage. This does not cause any objectionable error in secondary current within the operating range.

Basis of Application Table

How many capacitors can be safely applied? The recommended capacitor ratings listed in Table I are selected conservatively for the motor and its drive.

The overvoltage due to self-excitation usually will be within the maximum value (110 per cent) normally permitted for continuous motor operation. The transient torque occasioned by the use of reduced-voltage starters will be held to a reasonable value, with the possible exception of the manual autotransformer-type of starter, for which a suggested application procedure has been outlined.

The no-load power factor will be approximately 100 per cent and the motor full-load power factor will range from 95 to 98 per cent which gives sufficient power-factor improvement in most cases. The capacitor rating will range from 20 to 40 per cent of the full-load motor kilovolt-amperes; the smaller value applies to the high-speed motors which inherently have a higher power factor than slow-speed motors.

The data are confined to a single table for simplicity for the most common motor sizes in the 220-, 440-, 550-, and 2,300-volt rating. Some of the capacitor kilovolt-ampere values given in Table I do not conform to the present standard capacitor ratings for all voltage classes, but in such cases the next lower standard rating may be selected. The standard capacitor ratings for the common voltage classes are given in Table II.

Individual-Motor Power-Factor Improvement Versus the Group-Capacitor Method

The use of a common motor controller for switching the motor and the capacitor as a unit has become increasingly popular because of the elimination of one switching device and because of the operating convenience. The capacitor is switched in and out of service with its associated motor and therefore tends to eliminate overvoltage usually associated with light-load conditions in a plant. This unit-switching arrangement is economically attractive when only a few motors are involved or when there is no diversity among motors. In those plants having a large number of motors and diversity among motors in operation, such as is common in industrial plants with a large number of motor-driven equipments, group capacitors automatically switched

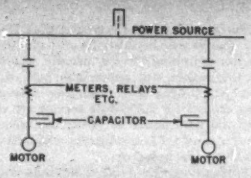


Figure 6. Circuit arrangement producing overvoltage in current-transformer secondary circuit

in several steps are usually more economical than individual-motor power-factor improvement. Operation with automatic control results in the functional equivalent of individual-motor power-factor improvement since the capacitors may be switched in blocks as dictated by the load requirements. Several papers have been written recently describing various types of control and their application for automatically switching capacitors.[7,8]

Several studies were made to determine the relative economics of plant power-factor improvement by means of capacitors with individual motors and the group-capacitor method.

The price comparisons were on the basis of the *same amount of total power-factor improvement.* For example, when all motors are connected to the line at the same time, so that the motor-diversity factor is one, the capacitor kilovolt-amperes required is the same for the two methods. When 50 per cent of the motors are on at the same time, corresponding to a motor-diversity factor of two, the group-capacitor rating need be only 50 per cent of the total capacitor kilovolt-amperes connected to all motors. The motor-diversity factor is the total motor-connected horsepower as related to the total horsepower of motors in operation.

The price ratio of individual capacitors to group capacitors was almost equal for the 220-, 440-, and 550-volt equipments for the same percentage of motors on the bus so the average price ratio for this voltage range was used. The price data were based on standard noninflammable liquid-filled capacitors used for power-factor improvement.

Example 1. Power-Factor Improvement of Individual Motors Versus Group Method of Power-Factor Improvement for Service Below 600 Volts

The price ratio of individual versus group capacitors for typical plants with motors from 3 to 50 horsepower is shown on Figure 7, plotted as a function of the per cent of motors in operation.

Note from curve *A* of Figure 7 that the group-capacitor method with manual switching is more economical than the individual-motor method even for the 100-per-cent condition when all motors are in operation. This is true because the price of capacitors in dollars per kilovolt-ampere is higher for small units than for larger units such as are commonly used with the group-capacitor method.

Curve *B* shows the price ratio when the automatic control and switching feature is incorporated with the group-capacitor method. (This is the operating equivalent of the individual-motor-capacitor method.) Note that even with the automatic control feature the group-capacitor method is economically more attractive than the individual-motor method.

Curve *C* shows the price relationship on the basis of the same capacitor cost, in dollars per kilovolt-ampere, for the two methods and clearly indicates the effect of diversity in the motors in operation.

Curve *A* will be very nearly correct for all applications. Low-voltage manual-switching devices are inexpensive so the cost of the

Table II. Standard Capacitor Ratings for Three-Phase 60-Cycle Units

	Individual Units			Standard Rack-Type Equipments*		
	Volts			Volts		
Capacitor Kva	230	460 and 575	2,400	230	460 and 575	2,400
0.5	x					
1.0	x	x				
2.0	x	x				
2.5	x					
5.0	x	x				
7.5	x					
10.0		x				
15.0		x				
15					x	
30					x	x
45					x	
60					x	x
90					x	
120					x	x
135					x	
180					x	x
240					x	
270					x	x
360					x	x

* Standard rack-type equipment as commonly used for group-capacitor installations. Larger banks are available for 2,400-volt service if more capacity is required. This listing is for standard racks of full capacity. Units may be removed in 7.5-kva units for 230-volt service and 15-kva units for 460-, 575-, and 2,400-volt service.

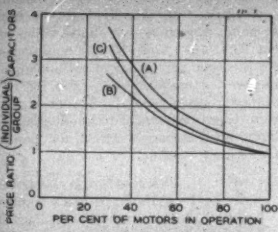


Figure 7. Price ratio (individual/group) capacitors versus per cent of motors in operation (for service voltages below 600 volts)

Curve A—Group capacitors with manual switching

Curve B—Group capacitors with automatic control and switching

Curve C—Equal capacitor cost in dollars per kilovolt-ampere for individual-motor and group-capacitor methods

switching device is a small part of the total capacitor-equipment cost. Curve *B* is representative for medium- and large-size industrial plants. For small plants or plants having a small connected motor load the price ratio will be lower since the cost of the automatic-control and switching feature becomes a large part of the capacitor-equipment cost when small capacitor banks are used. Generally, however, the automatic-control feature is not necessary in the small plants.

Example 2. Group Capacitors for Diversified Motor Load and Individual Capacitors for Selected Large Motors for Service Below 600 Volts

In those applications involving a large number of small motors and some large motors it is good practice to use group capacitors for the diversified motor load and individual capacitors for selected large motors. Large motors require large capacitor units which have a low unit price approaching that of the group-capacitor method. A low diversity factor among the large motors favors the individual method of power-factor improvement. If the motor-diversity factor is greater than about $1^1/_2$, the group-capacitor method is generally more economical.

The combination of group capacitors for the diversified load and individual capacitors for selected large motors offers the operating benefits associated with unit switching and thus helps prevent overvoltage during light-plant-load conditions. Consequently, automatic control usually is not required for the group capacitors used in such cases.

Example 3. 2,300-Volt Service

The group-capacitor method may not be economically attractive for 2,300-volt (or higher voltage) equipments unless the motor-diversity factor is greater than $1^1/_2$ to 2. This is true because the cost of the capacitor-switching device, usually a power circuit breaker, is an appreciable part of the total equipment cost. Another reason is that motors for 2,300-volt service are usually 100 horsepower or larger and require capacitors of the larger ratings which have a relatively low unit cost.

Applications involving 2,300-volt equipments should be considered individually.

Conditions Favorable to Individual-Motor Power-Factor Improvement

1. Capacitors automatically switched. Capacitors will be on only when needed and therefore will minimize plant-voltage rise at no load.

2. Application engineering simplified. Capacitor rating may be selected from Table I.

3. Flexibility for plant rearrangements. When plant changes require rearrangement of equipment the capacitor and motor can be moved together thus insuring proper power-factor improvement of the motor at any location.

4. Simplified installation. The capacitor and motor starter may be in a unit housing.

Conditions Unfavorable to Individual-Motor Power-Factor Improvement

1. Price higher for equipments below 600 volts. This is shown in Figure 7. The price comparisons are on the basis of actual selling price and not on the installed basis. If the installation cost were included, the relationship would probably be even more unfavorable to the individual-motor method since, generally, many small units cannot be installed as cheaply as a few large racks in a group. This is particularly true when the type of equipment furnished for group-capacitor installations is shipped complete as a unit ready for service. Even though the unit-type capacitor and starter is used, which does not require any additional installation expense for the capacitors, the group-capacitor method is cheaper.

2. Poor use of investment. This is true when all motors are not on at the same time. In the average industrial plant only 25–75 per cent of the motors are connected to the bus at the same time.

3. Lack of interchangeability of motor equipment. Usually 220-volt motors can be recommended for 440 volts but capacitors cannot. It is possible to use a 460-volt capacitor on 220 volts, but resulting in approximately 25 per cent of the rated kilovolt-amperes. A 230-volt capacitor cannot be used with a 440-volt motor, although two 230-volt capacitors can be connected in series for 440-volt motor service.

4. Limitations in location. Capacitors for power-factor improvement of 5- to 25-horsepower motors for 220-, 440-, or 550-volt service are relatively large compared with the motor and may require special consideration to location and mounting. However, this limitation may be avoided if the capacitor is located in the motor starter.

5. Improvement in over-all plant power factor limited. Power-factor improvement of individual motors has the limitation of improvement of the motor load only. The full-load motor power factor is improved to 95 to 98 per cent for the capacitor values recommended in Table I. If additional power-factor improvement is necessary for the plant, the additional capacitors required should not be switched with the motors. With the group-capacitor method, the entire plant power factor may be improved to the desired level.

Conclusions

1. In applying shunt capacitors to the terminals of induction motors for power-factor improvement, care should be exercised in selecting the capacitor rating to avoid:

(*a*). Overvoltage due to self-excitation.

(*b*). Transient torques.

(*c*). Overvoltage in current-transformer secondary circuits.

(*d*). Improper motor-overload protection.

2. The data in Table I are a practical guide in selecting the amount of capacitors to be switched with a motor.

3. Generally, economic considerations favor the group-capacitor installation for plant power-factor improvement when the service voltage is below 600 volts, the individual motors are small, and the motor-diversity factor is large. For other conditions individual comparisons should be made. For maximum operating benefits the group-capacitor method usually will consist of several blocks of capacitors automatically switched.

References

1. Why Not Switch Capacitors With the Load? J. W. Butler, E. B. Pope. *General Electric Review*, volume 41, August 1938, pages 366–9.

2. Self-Excitation of Induction Motors, C. F. Wagner. AIEE Transactions, volume 58, 1939, February section, pages 47–51.

3. Installing Power-Factor Condensers. *The Engineer*, December 4, 1942, pages 462–3.

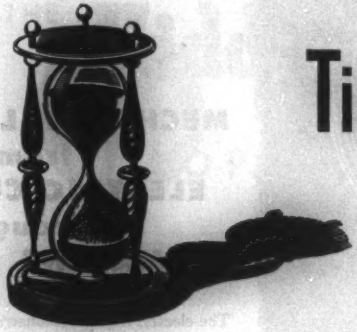
4. Can Capacitors Connected to Induction Motors Cause Dangerous Overvoltages? Ivar Herlitz. *Asea Tidning*, volume 27, November 1935, pages 174–5.

5. Overvoltage Protection of Current-Transformer Secondary Windings and Associated Circuits, R. H. Kaufmann, G. Camilli. AIEE Transactions, volume 62, 1943, July section, pages 467–72.

6. Analysis of Series-Capacitor Application Problems, J. W. Butler, C. Concordia. AIEE Transactions, volume 56, 1937, August section, pages 975–88.

7. Automatic Control and Switching Equipment for Capacitor Banks and Its Application, T. W. Schroeder, W. C. Bloomquist. AIEE Transactions, volume 63, 1944, September section, pages 649–54.

8. Extending the Use of Shunt Capacitors by Means of Automatic Switching, W. H. Cuttino. AIEE Transactions, volume 63, 1944, September section, pages 674–8.



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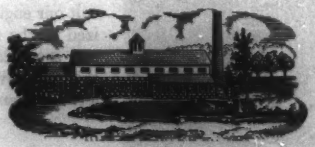

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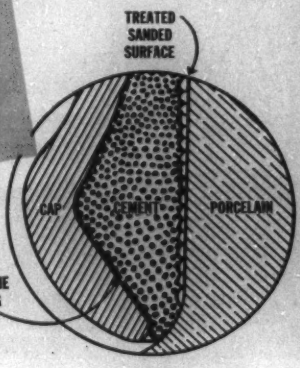
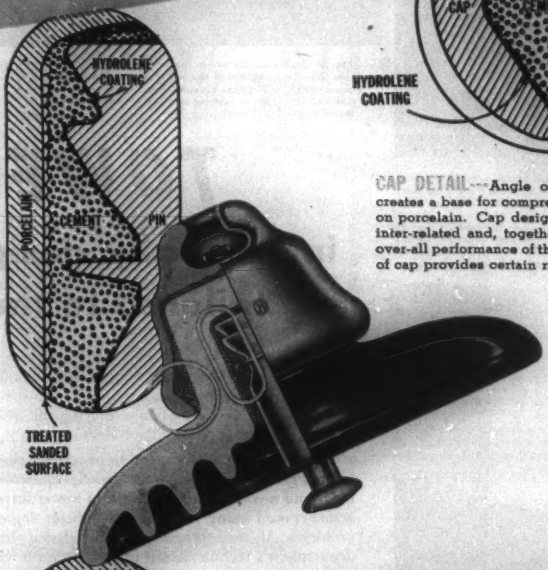


CAP DETAIL---Angle of internal lip of cap creates a base for compression forces that fall on porcelain. Cap design and pin design are inter-related and, together, contribute to the over-all performance of the insulator. Elasticity of cap provides certain relief.

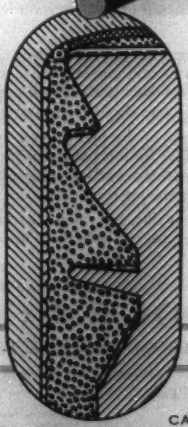


PIN DETAIL
(No Load)

Hydrolene coating on pin prevents adherence of cement so that pin is free to move. Cement is held in place adjacent to porcelain by intimate contact with an infinite number of grain particles in treated sanded surface.

PIN DETAIL
(Loaded)

Load causes slight vertical movement of pin. Thickness of Hydrolene coating provides some of the clearance for this purpose. Certain cement zones go into compression; transmitting this force to porcelain. Flexing of thin lower fin takes some load and provides for recovery.



2599-H

WE CAN scarcely tell you the story of a generation of research and development with a few pictures and lines of type, but here are the high spots of O-B suspension insulator design, in the 15,000-pound range. Inspection and testing is part of the story not pictured. Likewise, manufacturing control. These convert a sound principle into a consistent product--one that enables O-B to guarantee the minimum strength of the unit; and brand that unit with the kind of strength that counts, because you can count on it!

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Double-circuit strain and angle tower, about 12 feet high, located between two existing substations and to clear storage yard conveyor system

A tight-spot installation is typified by the new 113-foot angle tower at the extreme right. Anchored to its top are the power house double-circuits which here separate into two single circuits; one top-level circuit is diverted back of the old river crossing tower to the substation; the other is dropped some 30 feet and routed under power lines of the river crossing to the substation. The old river crossing tower and adjacent substation were also American Bridge projects.

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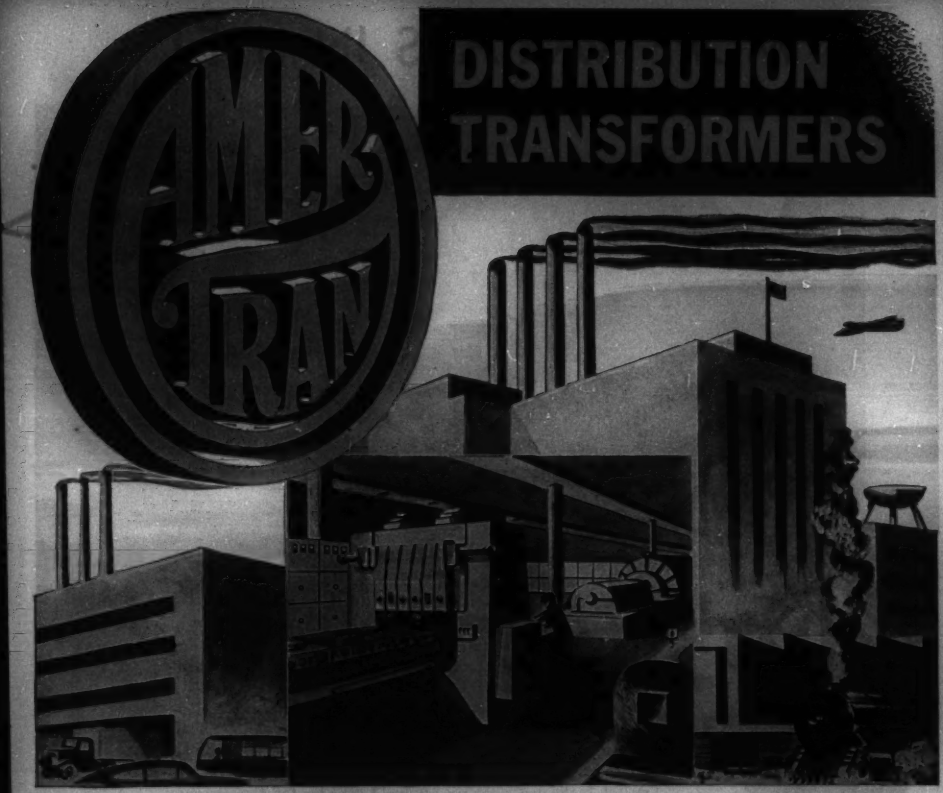

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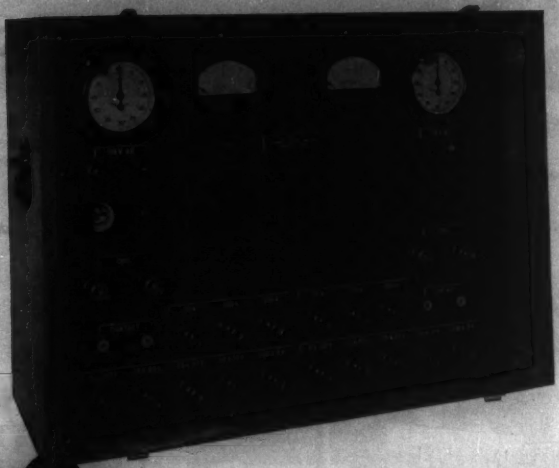

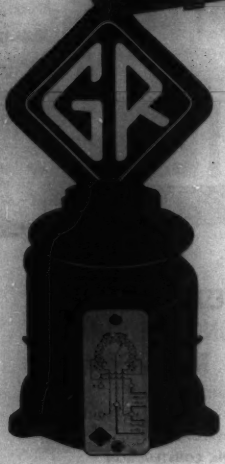

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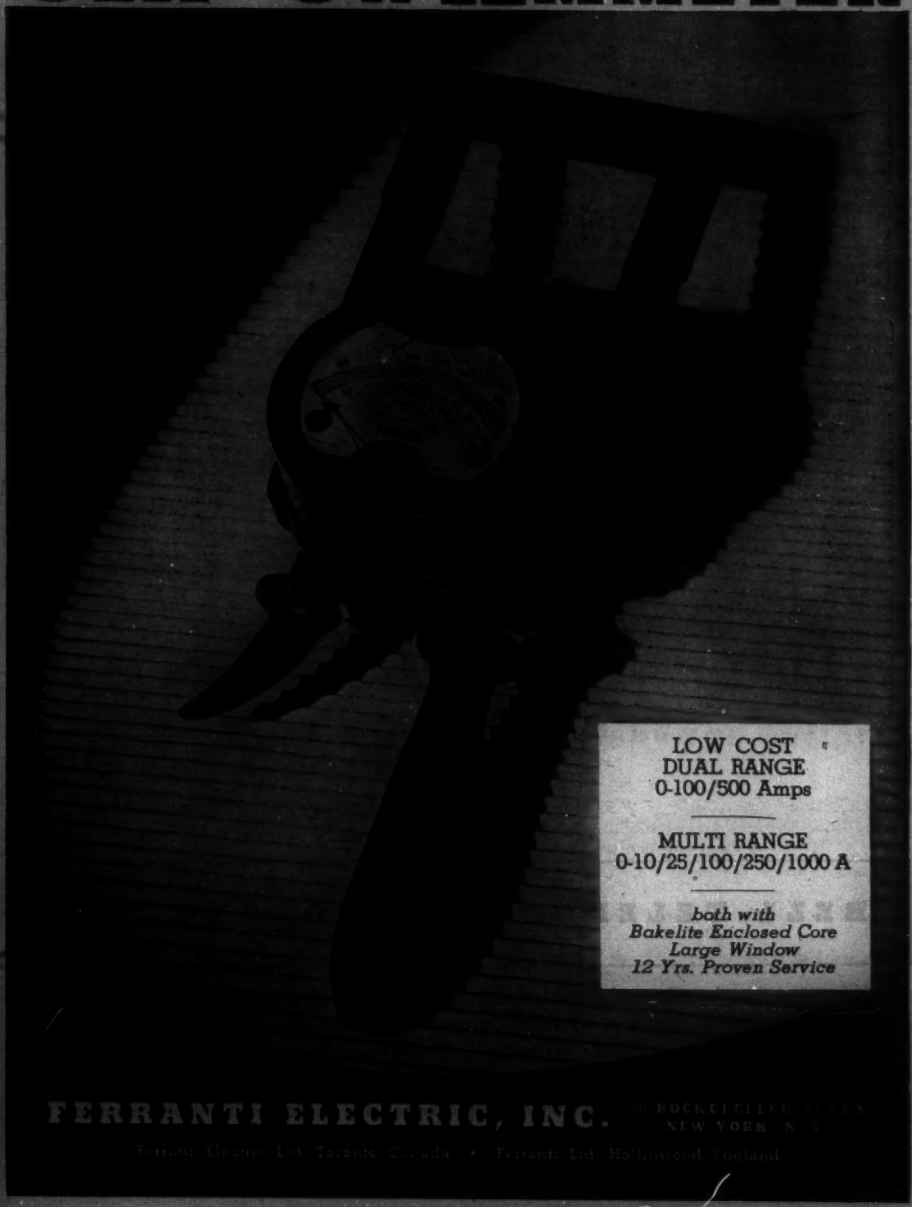

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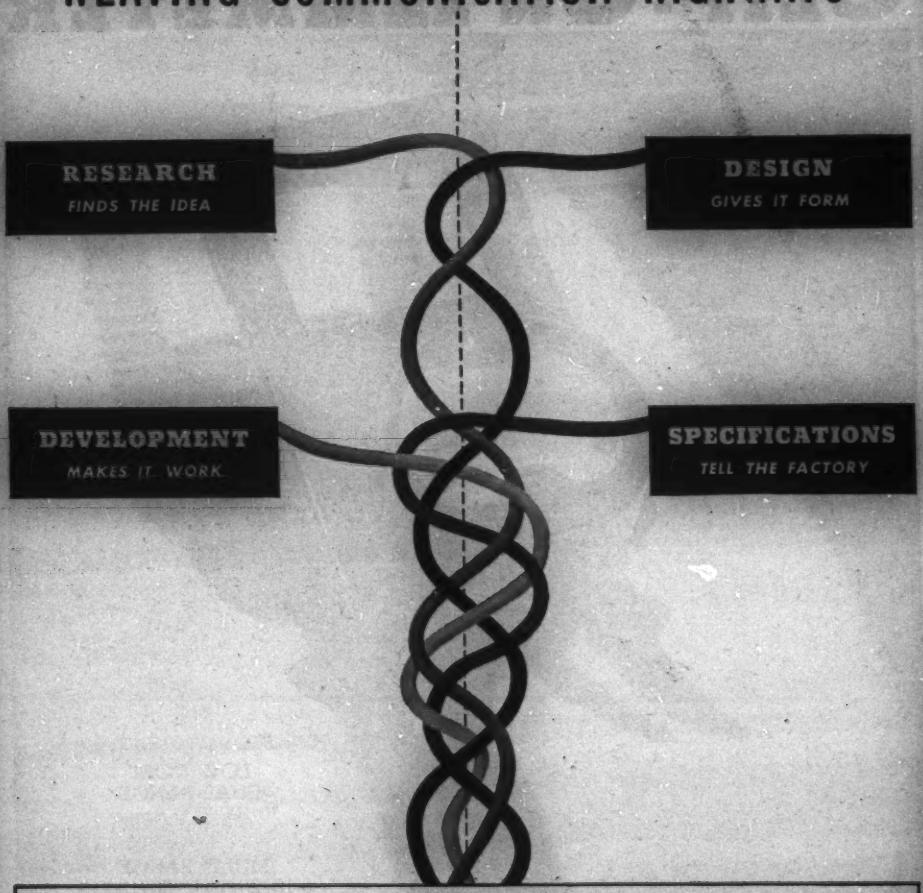

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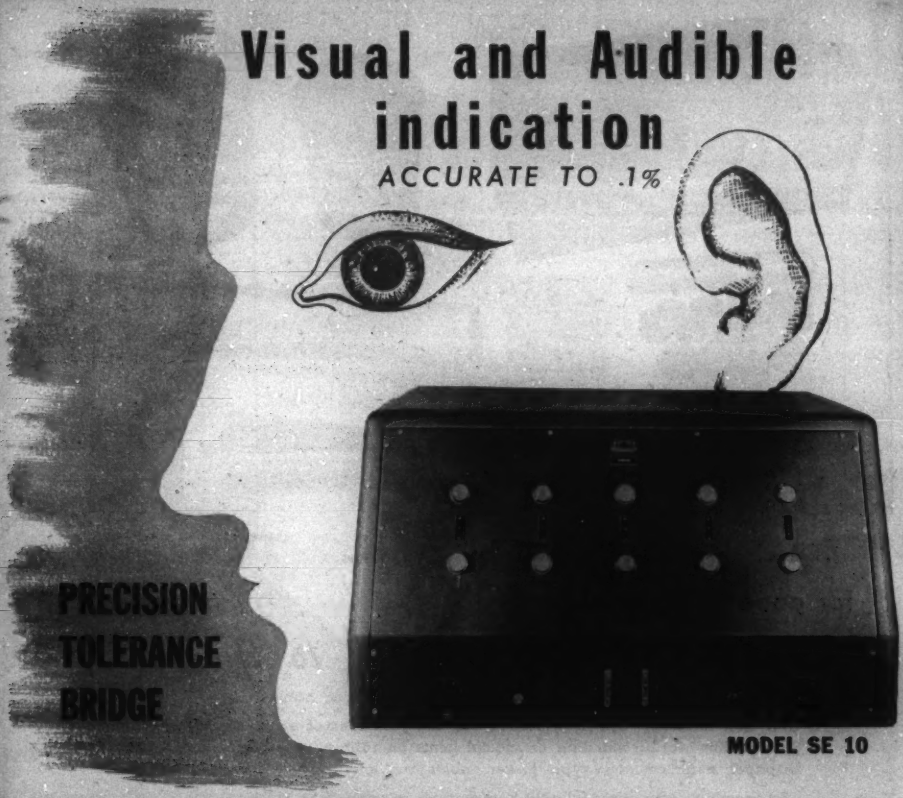

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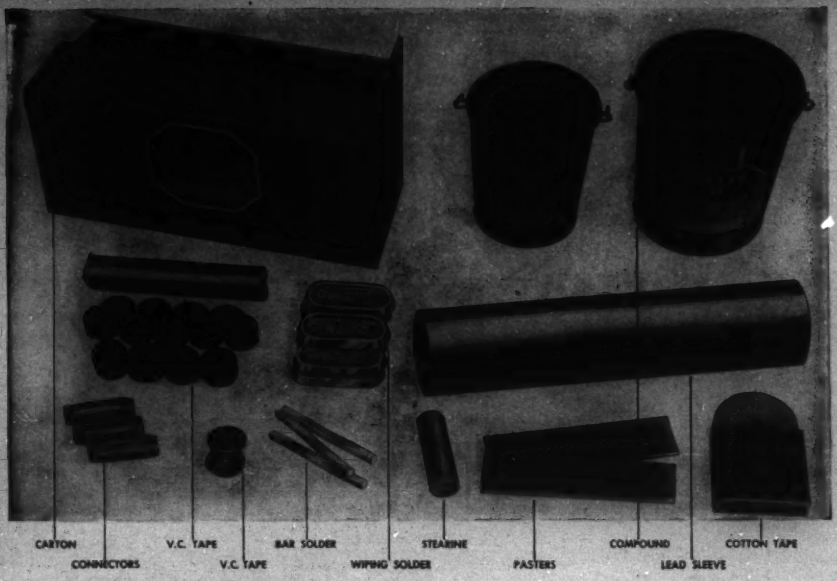

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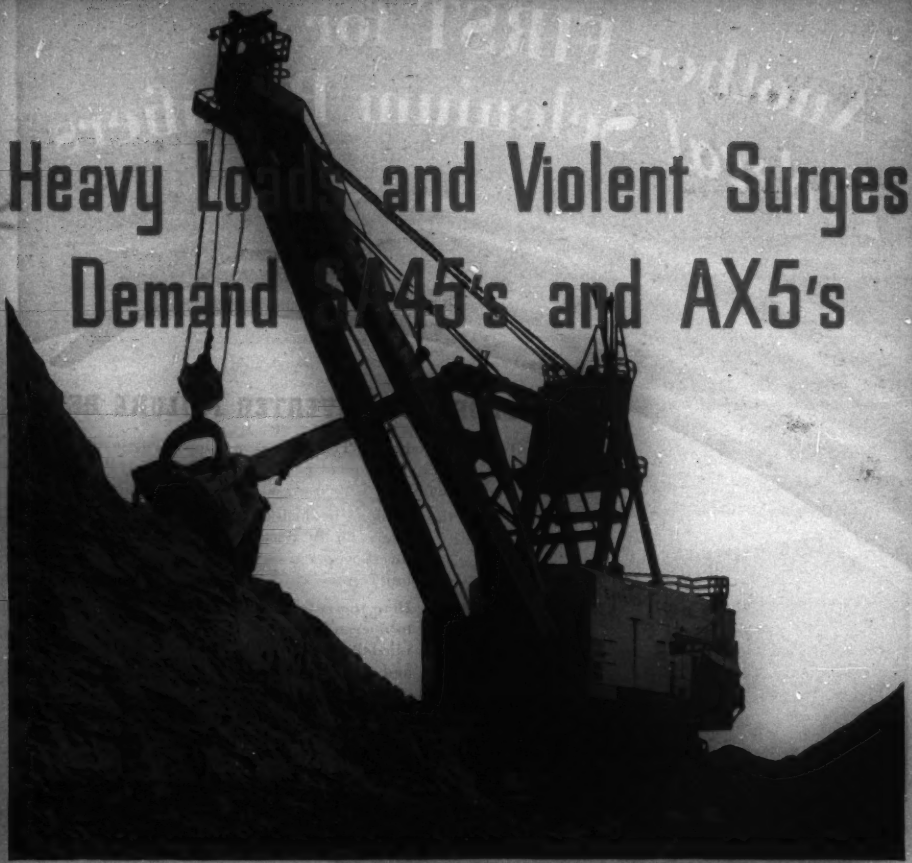

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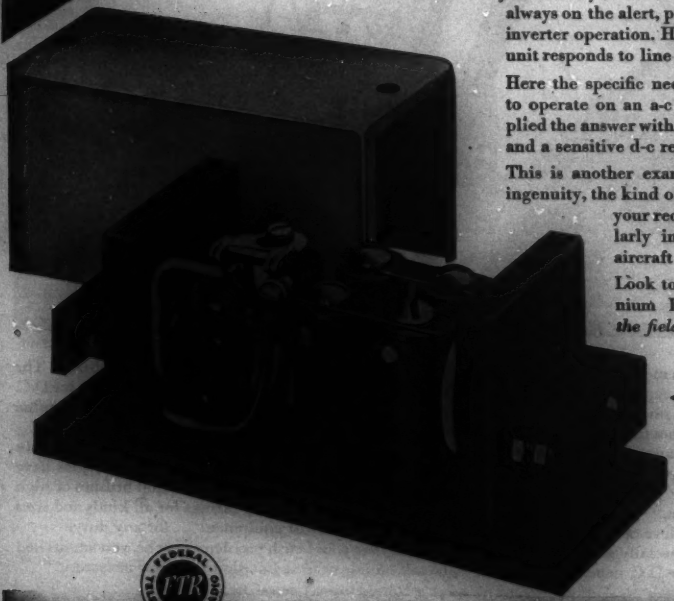

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By filling a definite need for a quick-drying finishing varnish, #27 Black Insulator, although comparatively new, has already proven itself in many organizations throughout the electrical industry. The excellent results obtained in its use, plus the many diversified and extraordinary applications on which this material has been utilized, all conclusively prove its merit. The following features are but a few of the reasons why #27 Black Insulator has met with wide-spread approval.

DRYING TIME: Air dries in amazingly short time of 5 to 10 minutes.

ADHESION: Excellent on metal, cambric, glass, asbestos, fibre board, sleeving and pre-varnished surfaces.

TOUGHNESS: Affords a tough, glossy film, which unlike most spirit varnish will not chip nor flake off. This finish provides great resistance to the abrasive action of dust particles.

RESISTANCE: Extremely oil and water resistant, withstanding the corrosive action of salt spray. Provides a high degree of heat resistance.

APPLICATIONS FOR DOLPH'S #27 BLACK INSULATOR

Field Coils	Switch Bases	Controller Shafts
Motor Frames	Solenoid Coils	Finger Blocks
Commutator Ends	Bus Bars	Fuse Tubes
Oil Reservoir Interiors	Collector Rings	Soldered Joints

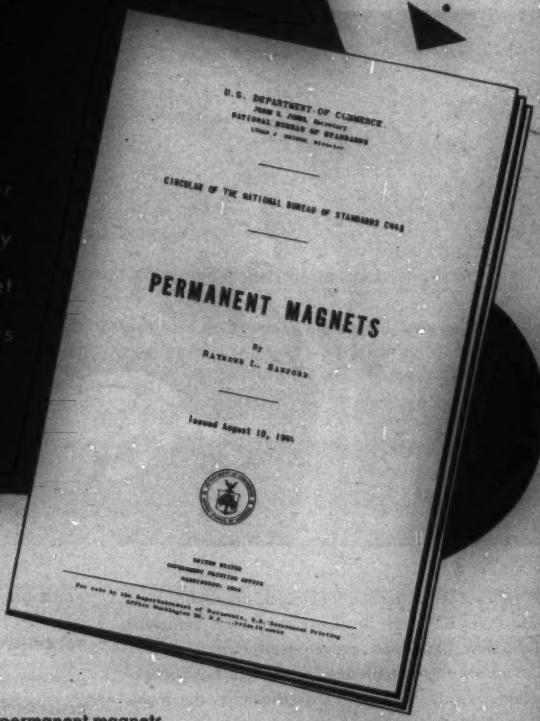
Insulating Dolph's *Varnish Specialists*

JOHN C. DOLPH COMPANY

168 EMMETT STREET • NEWARK 5, N. J.

YOURS!

Just write us, on your letterhead, for your copy of this valuable booklet on permanent magnets



● As a service to industry, The Arnold Engineering Company is "lending a hand" in the distribution of what Arnold engineers believe to be a very informative study on the subject of permanent magnets.

This 39-page book of permanent magnet theory, design data and references was published by the government. Arnold is pleased to make it available to you free of charge and without obligation. Write for it today!

THE ARNOLD ENGINEERING COMPANY

147 EAST ONTARIO STREET, CHICAGO 11, ILLINOIS

Specialists in the Manufacture of ALNICO PERMANENT MAGNETS

Only GE Offers All Three

Low-voltage Rectifiers

Where other manufacturers offer one or two of the three standard types of low-voltage rectifiers, General Electric is alone in supplying all three—an important fact to remember when next you need a rectifying unit. The reason: The most efficient type in one application may be least efficient on the very next application. It is in determining which type to use in each instance that G.E. can help you most—having all three types it can give impartial engineering advice on which one you should use. Full details from Section A-558-32, Tungar & Metallic Rectifier Division, General Electric Co., Bridgeport, Conn.

Hear the G-E radio programs: "The G-E All-Girl Orchestra," Sunday 10 P.M. EWT, NBC; "The World Today" news, Monday through Friday 6:45 P.M. EWT, CBS; "The G-E House Party," Monday through Friday 4:00 P.M. EWT, CBS.

GENERAL ELECTRIC

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SELENIUM

TUNGAR

Deep into many Arctic regions, electricity is being carried for the first time in history, thanks to Laytex-insulated wire.

Yes, worldwide war has subjected Laytex to many new conditions — not only freezing cold, but tropic heat, moisture, and shattering shock — greater strain and wear than any single wire was ever meant to withstand . . . to a degree far beyond what was expected.

Right now, the entire output of Laytex Wires and Cables is required for military needs. One day, Laytex will be once more available for Residential and Commercial Buildings, Police and Fire Alarm Systems, Communications, Signalling, Power, Control, and other exacting services.

Listen to "Science Looks Forward"—new series of talks by the great scientists of America—on the Philharmonic-Symphony Program, CBS network, Sunday afternoon, 3:00 to 4:30 E.W.T.

Rubber Insulation at its Best

U.S. Laytex

ELECTRICAL WIRES AND CABLES

Serving Through Science

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CARBON DISCS FOR OTHER APPLICATIONS
Other Stackpole types include carbon discs for electric brakes for trucks, speed governors—or wherever a little power must control a lot of power with utmost precision, smoothness, and dependability.

STACKPOLE

CONTINUOUSLY ADJUSTABLE CARBON RHEOSTATS

(CARBON PILES)

Under impetus of war requirements demanding resistance adjustments for more critical, more precise, smoother, and more dependable control than is possible with conventional variable resistance units, Stackpole engineering has developed the Continuously Adjustable Carbon Rheostat formed of carbon disc piles to a high degree of efficiency. Simply by changing the pressure applied to the pile, every possible resistance value within its range is available without opening the electrical circuit in which it is connected. The pressure to vary the resistance to the most critical adjustment may be applied electrically, mechanically, centrifugally or hydraulically. Uses range from both generator and line voltage regulator applications to remarkable speed control through governed field current on motors. Many other projects incorporating the Carbon Pile Resistor are now in the development stage.

Stackpole regularly supplies Carbon Piles in practically any length pile and diameter required. Resistance ranges have been materially expanded and a greater degree of resistance variation may now be obtained in a pile of a given size. Careful engineering control of manufacture assures a high degree of uniformity on a quantity production basis. Write for bulletin giving complete data.

STACKPOLE CARBON COMPANY

St. Marys, Pa.

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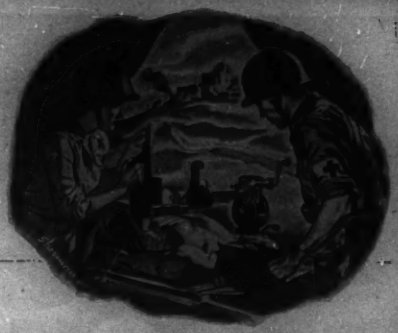
BRUSHES - CONTACTS *(All carbon, graphite, metal, and composition types)* IRON CORES RARE METAL CONTACTS
WELDING CARBON PRODUCTS VOLTAGE REGULATOR DISCS BATTERY CARBONS
PACKING, PISTON, and SEAL RINGS POWER TUBE ANODES, etc.

In a field hospital, a SURGEON uses a new x-ray machine that marks the exact location of the bullet, speeds life-saving behind the battle line.

... the name on the X-RAY MACHINE is Westinghouse.



In a laboratory an ENGINEER uses the instantaneous power of 75,000 thunderbolts to test giant circuit breakers that protect America's power systems.

... the name on the CIRCUIT BREAKER is Westinghouse.

In his tent a SOLDIER uses a bug bomb to destroy insect life – safeguarding health and increasing comfort in tropical jungles.

... the name on the BUG BOMB is Westinghouse.

In a war plant a WORKER uses an electromagnetic device to detect flaws in heat-treated bearing races – keeping our combat vehicles rolling on to victory.

... the name on the ELECTROMAGNETIC DEVICE is Westinghouse.

Westinghouse

PLANTS IN 25 CITIES OFFICES EVERYWHERE

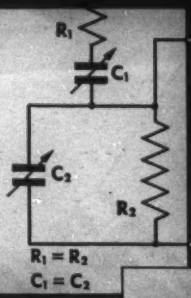
TODAY—Westinghouse products are serving in every battle, on every front, in the war against aggression.

TOMORROW—New processes and new materials... created under the stress of war... will mean better and longer-lasting Westinghouse products for a world at peace.

Tune in: JOHN CHARLES THOMAS—Sunday 2:30 pm, EWT, NBC. TED MALONE—Mon. Tues. Wed. Evening, Blue Network

hp laborat

This fundamental circuit is the key to -hp- audio oscillator efficiency



$$f = \frac{1}{2\pi RC}$$

The resonant frequency of this network is inversely proportional to the product of resistance and capacity. Thus wide change in resonant frequency is practical with commercially available condensers. A decade gang switch to change resistances enables operator to cover a wide range in the easiest possible manner. This circuit is the basic reason why -*hp*- Resistance-Tuned Audio Oscillators are so easy to use.

This resistance-capacity network is operated in conjunction with a

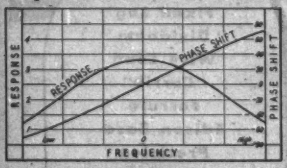


FIGURE 1

stabilized amplifier. Positive feedback is applied to this amplifier through the R-C network. The result is a very high effective "Q" for the circuit, which, combined with the phase shift characteristics of the network, provides an extremely stable output frequency. See Figure 1.

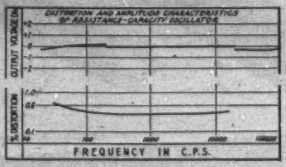


FIGURE 2

The unique balancing circuit automatically selects the proper operating point, keeps distortion at a remarkably low level, and maintains uniform output over the entire frequency spectrum. See Figure 2.

-*hp*- Audio Frequency Oscillators require no zero setting

It's just such engineered features as these that have made -*hp*- the outstanding laboratory instruments in the field today. Simplicity of operation... speed in making measurements without sacrifice of accuracy ... that's the keynote of all -*hp*- instruments. Write for information... -*hp*- engineers are at your service.

-*hp*- Resistance-Tuned AUDIO OSCILLATORS cover a wide range

-*hp*- Model 200-A
Frequency range, 35 cps to 35 kc. In 5 ranges: 35 to 350 cps, 350 to 3500 cps, 3500 cps to 35 kc.

-*hp*- Model 200-B
Frequency range, 20 cps to 20 kc. In 3 ranges: 20 to 200 cps, 200 to 2000 cps, 2000 cps to 20 kc.

-*hp*- Model 200-C
Frequency range, 20 cps to 200 kc. In 4 ranges: 20 to 200 cps, 200 to 2000 cps, 2000 cps to 20 kc, 20 kc to 200 kc.

-*hp*- Model 200-D
Frequency range, 7 cps to 70 kc. In 4 ranges: 7 to 70 cps, 70 to 700 cps, 700 to 7000 cps, 7000 cps to 70 kc.

-*hp*- Model 202-D
Frequency range, 2 cps to 70 kc. The Model 202-D is similar to the Model 200-D, with the addition of a 2-50 cps band covering approximately 200 degrees on the main tuning dial.

-*hp*- Model 200-I
Frequency range, 6 cps to 6000 cps. In 6 ranges: 6 to 20, 20 to 60, 60 to 200, 200 to 600, 600 to 2000 and 2000 to 6000 cps.

All the above models are available in cabinets or for relay rack mounting.

HEWLETT-PACKARD COMPANY

BOX 1042B • STATION A • PALO ALTO, CALIFORNIA

Audio Frequency Oscillators *Signal Generators* *Vacuum Tube Voltmeters*
Noise and Distortion Analyzers *Wave Analyzers* *Frequency Meters*
Square Wave Generators *Frequency Standards* *Attenuators* *Electronic Tachometers*

OHMITE RESISTORS

Many Types and Sizes Assure the Right Resistor for Each Control Job

Many critical control problems are being readily and successfully solved with Ohmite Resistors. That's because the extensive range of Ohmite types and sizes makes possible an almost endless variety of regular or special units to meet each need best.

Ohmite core sizes range from 2½" diameter by 20" long to 5/16" diameter by 1" long. Wide selection of stock units are available.

These rugged resistors have proved their worth under toughest operating conditions, in every field of action. Ohmite engineers are glad to help on today's and tomorrow's control problems.

TYPICAL UNITS

Fixed Lug
"Dividohm"
Wire Lead
"Corrib"
Ferrule
Edison Base
Precision
Bracket
Non-Inductive
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Strip

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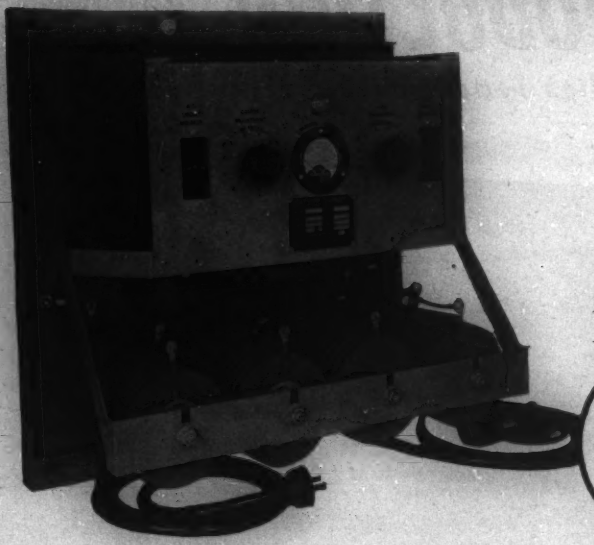
RHEOSTATS • RESISTORS • TAP SWITCHES

Send for Catalog and Engineering Manual No. 40
Write on company letterhead for this complete, helpful guide on resistors, rheostats, tap switches.
Address OHMITE, 4802 Flournoy, Chicago 44.

This New *LOW RIPPLE* D C Power Supply is a Trim, Businesslike Job!



Close-up of the Federal Telephone and Radio Corporation FTR-3106-S combination battery charger and DC power supply shows the simplicity and neatness of internal wiring, protected by Natvar Grade A-1 Tubing.

Federal's new FTR-3106-S is flexible. Used as a power supply, it will furnish direct current from 5 to 80 volts in 121 steps, at 12 amperes, maximum. As a battery charger it will handle from 1 to 24 two-volt storage cells at a maximum current of 12 amperes.

Selenium Rectifiers — pioneered by Federal — provide the efficient, dependable means of converting single phase AC power to DC power. Conservative design which eliminates the need for fans or other moving parts, plus heavy overload capacity, along with the wide voltage range makes it suitable for a variety of laboratory and experimental work, as well as a rugged source of rectified DC for production equipment.

Natvar flexible tubing is used to protect the wiring of FTR-3106-S because of its high dielectric and mechanical strength, and because of its high uniformity.

What are your insulation requirements? Write, wire or phone us for deliveries, either from stocks located near you or from our own.

Natvar

- Varnished cambric — straight cut and bias
- Varnished cable tape
- Varnished canvas
- Varnished duck
- Varnished cellulose acetate
- Varnished special rayon
- Varnished Fiberglas cloth
- Varnished papers
- Varnished tubings and sleeving
- Varnished identification markers
- Lacquered tubings and sleevings
- Extruded vinyl tubing
- Extruded vinyl identification markers

Write for Catalog No. 20

THE NATIONAL VARNISHED PRODUCTS Corporation

TELEPHONE RAHWAY 7-2171 — CABLE ADDRESS NATVAR: RAHWAY, N. J.

203 RANDOLPH AVENUE ★ WOODBRIDGE NEW JERSEY

IN PRODUCTION *Now*

on DC Silicone High Temperature Electric Insulation

DC 993 Silicone Mica-Glas approximately doubles the heat-resistant qualities of Class B electrical insulation.

No longer is its application limited to laboratory experiments. The oven shown above, with a temperature range between 200° and 600° F., *is in full production* in our plant.

If the life of your rotating electrical equipment is reduced by heat, humidity or corrosive atmosphere, if overloading causes premature failure or if coil maintenance cost is excessive we can help you. Let us supply you with Silicone Mica-Glas coils, Silicone insulating materials, Silicone varnish or complete Silicone Mica-Glas re-winds.

The large stator on the skid truck in the picture above is from an 800 HP 1800 RPM 2300-volt 3-phase 60-cycle induction motor which operates a draft fan in the top of a power house, where very high ambient temperatures exists.

The wound rotor in the right rear is from the same motor.

The circular coil to be baked on the skid at the right is an induction heating coil. It normally operates with a current of 1765 amperes at 500 volts.

The coil suspended in the rear is wound of rectangular copper tubing. In use, it is water cooled and is connected to a 200-Kva 500-volt 2000-cycle generator. Blanks for 500-lb. bombs are heated to red heat by this coil within less than one minute.

NATIONAL ELECTRIC COIL COMPANY

COLUMBUS 16, OHIO, U. S. A.

WINNING COMBINATION

for Maximum Efficiency with

PEDIGREE

Insulating

VARNISHES

IMC ENGINEER CAN POINT IT OUT TO YOU

Maximum efficiency of electrical windings can only be obtained with the correct combination of insulating materials. Pedigree Insulating Varnishes, as manufactured by The P. D. George Company, compensate for the deficiencies of the other material in the combination and insure superior performance.

There is a "balanced" Pedigree product for every electrical application, providing excellent mechanical, chemical, thermal, and electrical protection.

The I. M. C. engineer is qualified to consider the operating requirement and processing facilities after which the correct product providing the longest life is recommended.

A copy of the latest catalog of The P. D. George Company and the latest descriptive data on all of the standard Pedigree Insulating Varnishes is available on request. Investigate the products with a Pedigree.

OTHER IMC PRODUCTS

Macallen Mica Products — Vortex Varnished Cloth and Tapes — Varslot Combination Slot Insulation — Varnished Silk and Paper — Fiberglas Electrical Insulation — Manning Insulating Papers and Press Boards — Dow Corning Silicones — Dieflex Varnished Tubings and Saturated Sleevings of Cotton and Fiberglas — National Hard Fibre and Fishpaper — Phenolite Bakelite — Adhesive Tapes — Asbestos Woven Tapes and Sleevings — Cotton Tapes, Webbings, and Sleevings — Wood Wedges.

SERVICE TO MANUFACTURERS IN THE MIDWEST

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What are the uses of Carbonyl Iron Powders?

The examples illustrated may suggest more specific applications of G.A.F. Carbonyl Iron Powders to many electrical design engineers. Other members of the profession, however, may desire a more detailed description of these powders. This is given below.

G.A.F. Carbonyl Iron Powders are obtained by thermal decomposition of iron penta-carbonyl. There are five different grades in production, which are designated as "L," "C," "E," "TH," and "SF" Powder. Each of these five types of iron powder is obtained by special process methods and has its special field of application.

The particles making up the powders "E," "TH," and "SF," are spherical with a characteristic structure of concentric shells. The particles of "L" and "C" are made up of homogenous spheres and agglomerates.

The chemical analysis, the weight-average particle size, the "tap density" (i.e. the density of the powder after a container is filled with loose powder has been tapped in a prescribed manner), and the apparent density or bulking factor as determined in a Scott Volumeter are given in the following table for the five different grades:

TABLE I

	% Carbon	% Oxygen	% Nitrogen	% Iron	Tap Density	Apparent Density (Scott)
L	0.03 – 0.09	0.1 – 0.3	0.001 – 0.01	99	3.5 – 4.5	1.5 – 2.1
C	0.01 – 0.13	0.1 – 0.3	0.01 – 0.1	99	3.5 – 4.5	2.5 – 3.5
E	0.03 – 0.09	0.45 – 0.60	0.6 – 0.7	98	3.5 – 4.5	3.5 – 3.9
TH	0.5 – 0.6	0.5 – 0.7	0.5 – 0.6	98	4.0 – 4.7	2.5 – 3.5
SF	0.5 – 0.6	0.7 – 0.8	0.3 – 0.4	98	3.7 – 4.3	2.5 – 3.5

Spectroscopic analysis shows that other elements, if any, are present in traces only.

Carbonyl Iron Powders are primarily useful as electromagnetic material over the entire communication frequency spectrum.

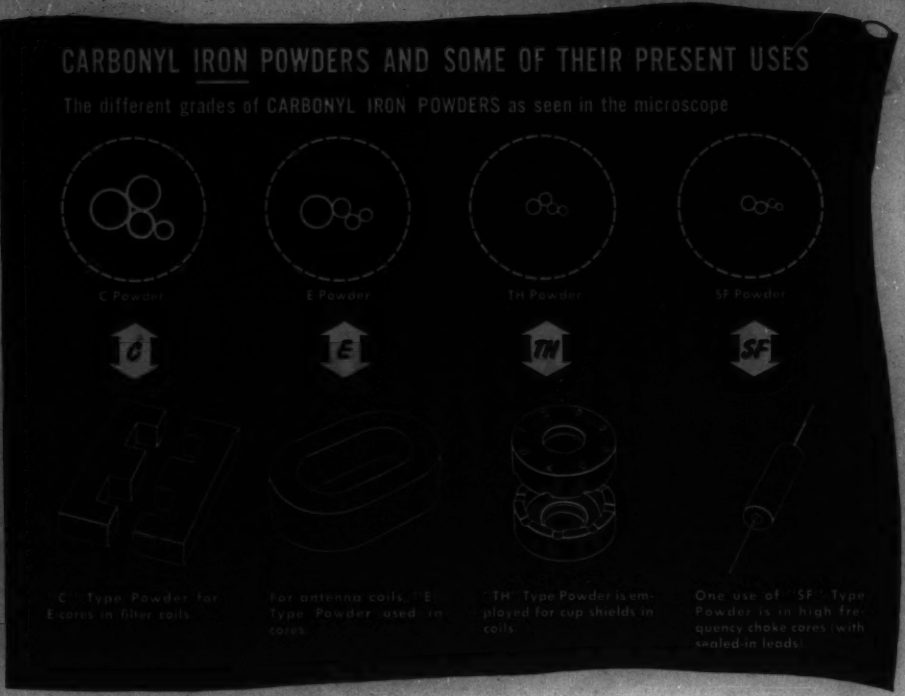

CARBONYL IRON POWDERS AND SOME OF THEIR PRESENT USES
The different grades of CARBONYL IRON POWDERS as seen in the microscope
C Powder
E Powder
TH Powder
SF Powder
C
E
TH
SF
C Type Powder for E-cores in filter coils.
For antenna coils E Type Powder used in cores.
TH Type Powder is employed for cup shields in coils.
One use of SF Type Powder is in high frequency choke cores (with sealed-in leads).

Table 2 below gives relative Q values (quality factors) and effective permeabilities for the different grades of carbonyl iron powder. The values given in the table are derived from measurements on straight cylindrical cores placed in simple solenoidal coils. Although the data were not obtained at optimum conditions, the Q values as expressed in percentage of the best core give an indication of the useful frequency ranges for the different powder grades.

"L" and "C" powders are also used as powder metal-

Carbonyl Iron Grade	Effective Permeability at 1 kc	Relative Quality Factor at 16 kc	150 kc	500 kc	1 Mc	100 Mc
L	6.16	100	96	93	43	1
C	5.45	94	100	96	73	3
E	3.89	81	94	100	97	20
TH	2.97	81	93	93	100	64
SF	2.12	63	75	75	84	100

lurgical material because of their low sintering temperatures, high tensile strengths, and other very desirable qualities. (Sintering begins below 500°C and tensile strengths reach 150,000 psi.)

Further information can be obtained from the Special Products Sales Dept., General Aniline & Film Corporation 435 Hudson Street, New York 14, N. Y.

G.A.F. CARBONYL IRON POWDERS

HOW EXCELLENCE IS BUILT INTO

Sangamo

MICA CAPACITORS

• The above picture shows a group of operators assembling by hand the mica films and foil used in the manufacture of capacitors of small capacitance values. Special assembly fixtures are used to insure accurate positioning of component parts.

SANGAMO ELECTRIC

ESTABLISHED 1906 • MICA CAPACITORS

★ *This operator is assembling mica and metal foils to form a unit which constitutes the essential element of a mica capacitor. Hand operators are utilized where only a few sheets of mica and foil are required for units of low capacitance value. Specially trained operators insure proper placing of component parts, resulting in a finished product of high quality.*

Hand Stacking

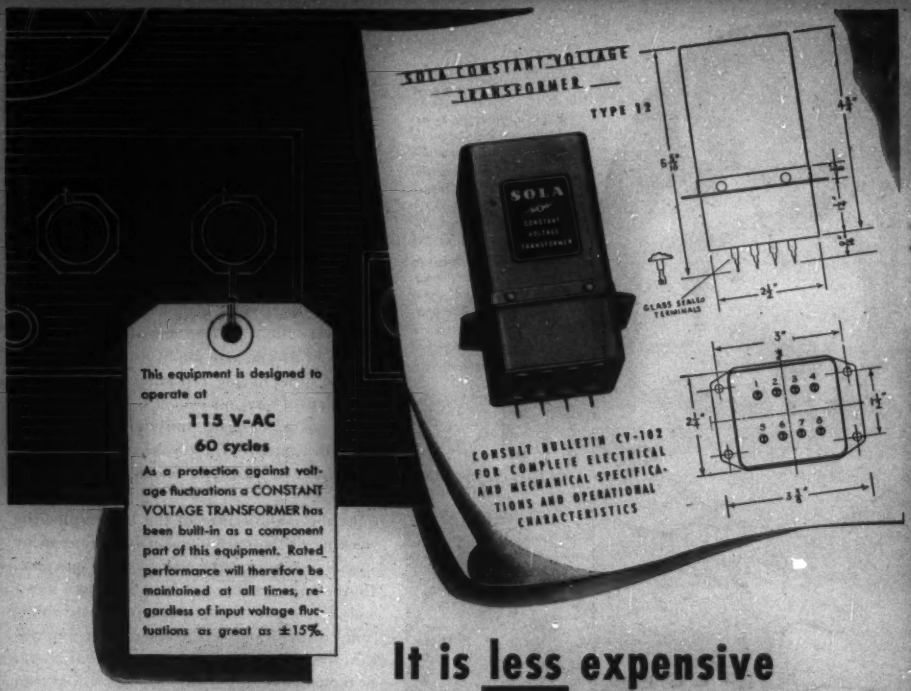
Capacitors utilizing mica as a dielectric are manufactured in a complete range of sizes, from very tiny wire lead units having capacity values of as low as 5 mmfd. to large ceramic-housed units having capacities which may be as high as several microfarads. Voltage ranges, too, vary from small units having dielectric strength test of only 300 volts or less, to those units built to withstand 40,000 or 50,000 volts or more.

In the manufacture of the large units, the stacking of the mica element is performed by special machines designed for that purpose. In the manufacture of the very small units with low capacitance values, plates are sometimes utilized and it is, consequently, impractical to stack these with automatic equipment. In these cases, hand operators are utilized who become very skillful in stacking the alternate layers of foil and mica, and in keeping the exact alignment so necessary for the production of a good capacitor.

Where special characteristics are required, a silver deposit is sometimes placed on the mica and fired on, and thus becomes the conducting plate in the capacitor assembly. By firing silver on mica, very intimate contact is made with the dielectric, and as a consequence, stability, that is, capacitance drift, is improved and special temperature characteristics obtained. It is essential that the silver coating be of uniform texture, with clean, well defined edges, so as to prevent excessive corona and ultimate voltage breakdown of the capacitor unit. Sangamo builds many thousands of the silver mica capacitors each day and is well equipped to produce and test these units in accordance with the required characteristics.

☆

COMPANY SPRINGFIELD ILLINOIS


SOLA CONSTANT-VOLTAGE TRANSFORMER
TYPE 12
SOLA
GLASS SEALED TERMINALS
CONSULT BULLETIN CV-102 FOR COMPLETE ELECTRICAL AND MECHANICAL SPECIFICATIONS AND OPERATIONAL CHARACTERISTICS
This equipment is designed to operate at
115 V-AC
60 cycles
As a protection against voltage fluctuations a CONSTANT VOLTAGE TRANSFORMER has been built-in as a component part of this equipment. Rated performance will therefore be maintained at all times, regardless of input voltage fluctuations as great as ±15%.

It is less expensive to provide built-in CONSTANT VOLTAGE

When you specify a SOLA Constant Voltage Transformer as a built-in part of your equipment there will be several components that you can write off your cost sheets. That's your first saving.

Now, estimate the number of anticipated service calls that would result from unstable voltages during your guarantee period. Write those off too.

Then—you can write off some sales expense, because equipment that provides its own protection against voltage sags and surges, and maintains laboratory efficiency in its operation is easier to sell.

This Type 12 SOLA Constant Voltage Transformer, is one of several small, compact units that have been designed specifically for chassis mounting. They are being successfully used by manufacturers of many types of electrical and electronic equipment. Where volume is indicated their cost is surprisingly low.

If unstable voltages have been a problem in war-time imagine what will happen when all of the much publicized electrical and electronic gadgets make their appearance on a peace-time market.

Consultation with our engineers *now* may give you the competitive advantage you are seeking for your peace-time sales.

SOLA Constant Voltage Transformers

To Manufacturers:
Built-in voltage control guarantees the voltage called for on your label. Consult our engineers on details of design specifications.
Ask for Bulletin *ACV-103*

Transformers for: Constant Voltage • Cold Cathode Lighting • Mercury Lamps • Series Lighting • Fluorescent Lighting • X-Ray Equipment • Luminous Tube Signs Oil Burner Ignition • Radio • Power • Controls • Signal Systems • Door Bells and Chimes • etc. **SOLA ELECTRIC CO., 2525 Clybourn Ave., Chicago 14, Ill.**

FOR SMALL STATION OR LARGE...

Alcoa Aluminum

BUS BARS

Advantages offered by Alcoa Aluminum bus bars apply to all types and sizes of stations. In the two pictured here, for example—the stiffness and light weight of Alcoa tubular bus permits wide spacing of supports. This results in simpler construction, with economies in labor and materials.

Alcoa Aluminum bus bars and fittings are available for WPB-approved projects. As always, Alcoa engineers will be glad to assist you in selecting the proper size and type of conductors and fittings. Write ALUMINUM COMPANY OF AMERICA, 2149 Gulf Building, Pittsburgh 19, Pennsylvania.

ALCOA ALUMINUM

See How Easy it Is to

ROUTINE CONTACT INSPECTION IN 3 QUICK STEPS ON OILLESS "RUPTAIR" MAGNETIC AIR BREAKER

1 LOWER BREAKER. Photo shows "Ruptair" magnetic air breaker in operating position (at right) and in the lowered disconnect position. The breaker is easily lowered with manually or electrically operated crank-hoist.

2 WITHDRAW BREAKER. In disconnect position, the "Ruptair" breaker can be placed on a transfer truck, and pulled out into the aisle. For safety, shutters to isolate disconnect contacts are automatic in operation.

3 REMOVE SIDE PLATES. Finally, light-weight insulating barriers are removed, each barrier being held in place by two cap-screws. Since the arc chute is above the contacts, it need not be disturbed for contact inspection.

AS A MODERATE capacity, oilless circuit interrupter, the "Ruptair" breaker is gaining increased popularity among operators. Elimination of oil means many more repetitive operations without maintenance . . . reduced fire hazard . . . less danger from breaker failure.

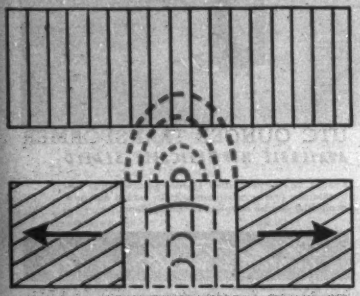
In addition to these advantages, and simplest inspection of any magnetic air breaker, the "Ruptair" breaker combines space saving vertical lift construction with horizontal contact separation, shown at top of opposite page. "Ruptair" circuit breakers are built in standard ratings of 5 kv and below, 150,000 kva interrupting capacity and below, for installation in metalclad switchgear, cells, or cubicles. To get the full story, write Allis-Chalmers, Milwaukee 1, Wis.

♪ *Tune in the Boston "Pops", Blue Network, Saturdays at 8:30 pm, E.W.T.*

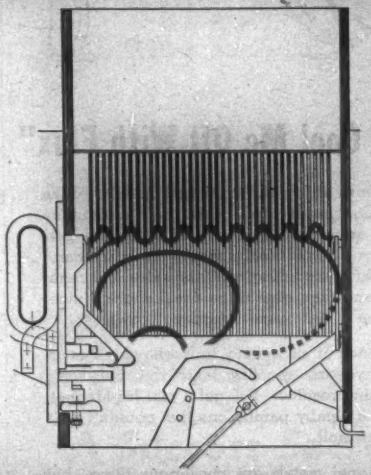
Inspect

A "RUPTAIR" MAGNETIC AIR CIRCUIT BREAKER

WITH HORIZONTAL SEPARATION OF BREAKER CONTACTS, MAINTENANCE AND OPERATION ARE SIMPLIFIED



SINCE THE ARCING contacts on a "Ruptair" magnetic air circuit breaker are separated in the horizontal direction, natural thermal effect assists the arc into the arc chute . . . no complex interrupting structure is required! Position of arc chute *above* contacts makes it possible to inspect contacts without removing the chute. Maximum interrupting effectiveness is achieved in the "Ruptair" circuit breaker, without departing from ideal simplicity of design.



RUPTAIR BREAKER HAS UNIQUE DESIGN

THE RUPTAIR breaker depends for its high efficiency throughout interrupting current range on several design factors . . . coordination of horn-shaped moving contact and arc runner for quick transferral of the arc . . . establishment of a strong magnetic field in the breaker before actual contact separation . . . and special design of the arc chute.

Why Allis-Chalmers offers all 3 types of Circuit Breakers

Ever hear of "special theater modifications"? That's a military term, and refers to the adaptation of aircraft to unusual flying conditions, such as are encountered in Central Alaska, or in torrid tropical climates.

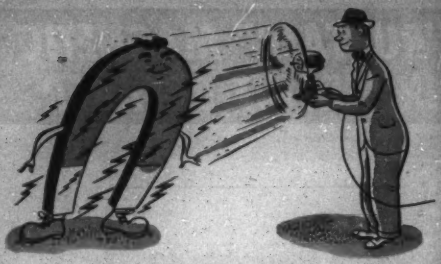
An airplane built for special theater operations often differs in practically every detail from a plane designed for duty under normal atmospheric conditions. That is, the Army and Navy have learned that *one* type of plane can't function in *all* theaters of war!

For the same reasons, Allis-Chalmers engineers know that one type of circuit breaker won't do the job in all the varied environments encountered in industry.

Therefore, it is an Allis-Chalmers switchgear policy to offer *all three* basic types of circuit interruptors — oil, magnetic air, and air blast breakers — for unrestricted customer choice. Neither by price penalties, or any other means, does Allis-Chalmers seek to coerce buyers into selecting any *one* type of breaker.

Thus the customer has a means of expressing his circuit breaker preference, based on intimate knowledge of local operating conditions. And indirectly, through the medium of free choice, he influences the future trend of switchgear development. A 1863

ALLIS-CHALMERS
MILWAUKEE

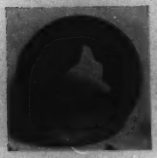


"Just Cool Me Off With Flux"

It's a funny thing about magnet metals. Take ALNICO-V for example. You can design the magnet scientifically, cast it of the metal perfectly, grind it to final shape with every care, heat treat it according to all the rules and regulations and then give it the usual shot of juice. Yes, you'll get some magnetic power.

But quench it in a field through which magnetic rays are shooting and you get some astonishing results. You get a real He-Magnet, not just a namby pamby one that couldn't lift a horseshoe nail.

Yes, magnet metals are mysterious things but our engineers know about all there is known about them to date. We'll be glad to apply our knowledge to the design and manufacture of your magnet.



Typical of the many varieties of Permanent Magnets designed and made by CINAUDAGRAPH.

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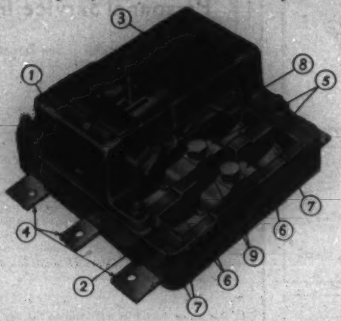

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5—Heavy copper bridges for movable contacts
6—Heavy silver main contacts
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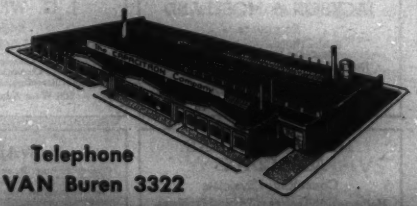

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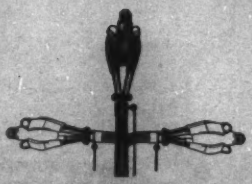

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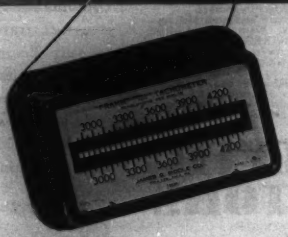

. . . shows

Turbine speed

This is the turbine end of a 300 kw turbine-generator unit built by the Moore Steam Turbine Division of the Worthington Pump and Machinery Corporation. Mounted on the panel board to give a continuous indication of turbine speed is a Frahm Resonant Reed Tachometer.

Frahm Tachometers are chosen for this and many similar applications because of their extreme simplicity of construction and unfailing accuracy. Having no belts, shafts, gears, springs or delicate parts there is nothing to wear out, and they can be depended upon to function faithfully without attention—year after year after year.

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Response characteristic charts like the above (test at 24 volts) are found in Solenoid Bulletin.

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As a reliable means of controlling or operating various devices, they are used for retarding magnetos in starting engines, operating hydraulic valves and mechanical clutches, firing machine guns, arming and releasing bombs, dropping auxiliary fuel tanks, locking retracting gears, film-winding mechanisms and for shutter control on special cameras. These are only a few of the possible applications.

A copy of the Cannon Electric Solenoid Bulletin—34 pages of diagrams, data and photos of the complete line will be sent free for the asking. Address Dept. A-311, Cannon Electric Development Co., 5209 Humboldt Street, Los Angeles 31, California.

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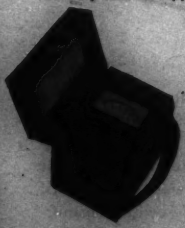

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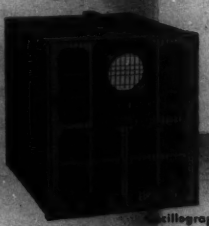

Oscillograph

• In maintaining the highest standard of excellence the one and only HICKOK aim must always be the building of instruments that tell all the truth all the time. When quality is built up to a high standard instead of down to a price, the user has greater confidence in his work.

Whether you are selecting tube and set testers, signal generators, oscillographs, volt-ohm-milliammeters or any other service equipment, remember that the standard of quality for a third of a century has never been excelled. Having pioneered the major new developments and vindicated maximum accuracy and dependability, HICKOK equipment has been specified by the armed forces in both world wars. We are still bending every effort to speed the war program and trust it will not be long until we can again take care of your civilian needs with the service equipment that is held in highest esteem. Write for Radio Equipment catalogue.

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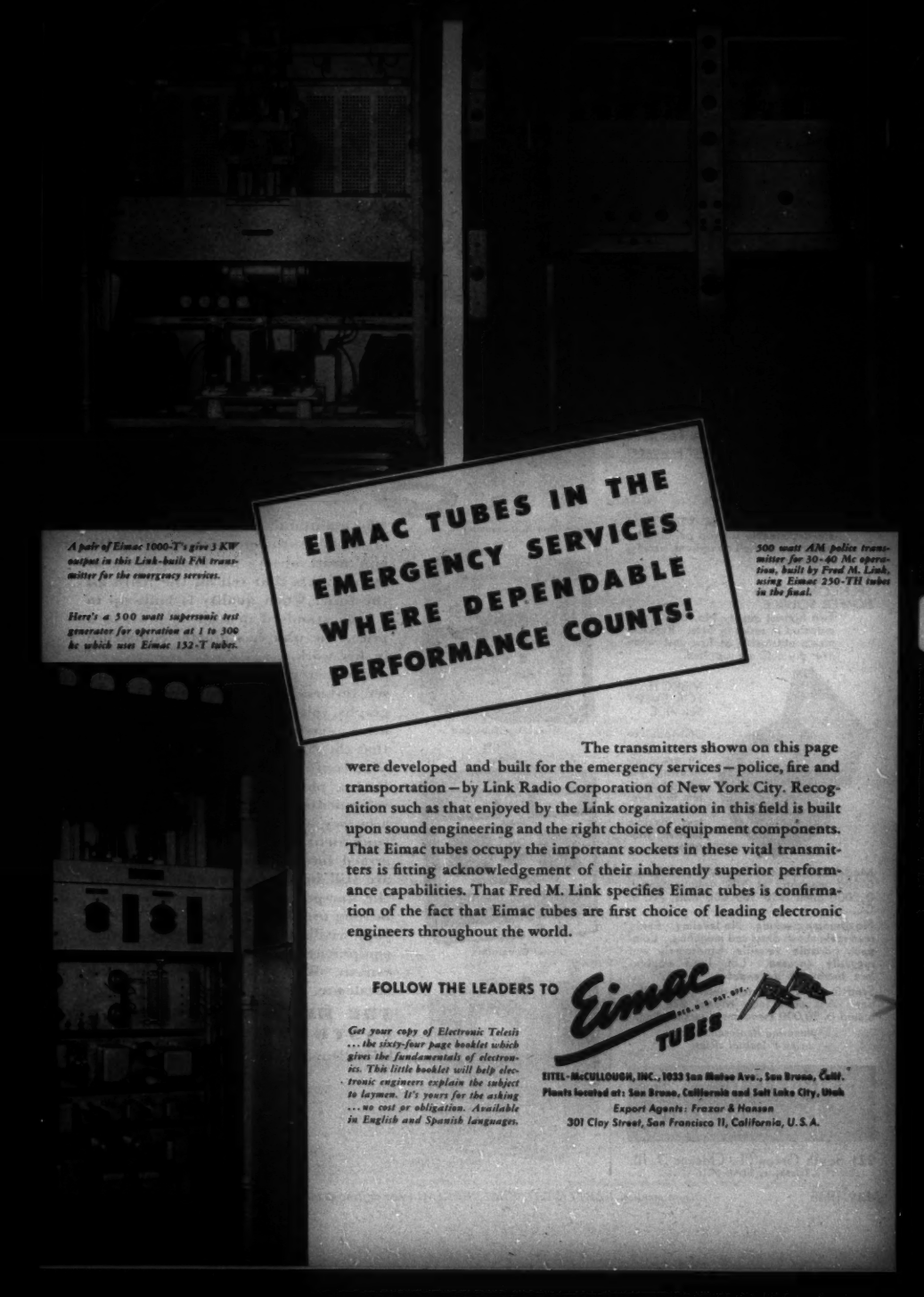

EIMAC TUBES IN THE EMERGENCY SERVICES WHERE DEPENDABLE PERFORMANCE COUNTS!

A pair of Eimac 1000-T's give 3 KW output in this Link-built FM transmitter for the emergency services.

Here's a 500 watt supersonic test generator for operation at 1 to 300 kc which uses Eimac 152-T tubes.

500 watt AM police transmitter for 30-40 Mc operation, built by Fred M. Link, using Eimac 250-TH tubes in the final.

The transmitters shown on this page were developed and built for the emergency services—police, fire and transportation—by Link Radio Corporation of New York City. Recognition such as that enjoyed by the Link organization in this field is built upon sound engineering and the right choice of equipment components. That Eimac tubes occupy the important sockets in these vital transmitters is fitting acknowledgement of their inherently superior performance capabilities. That Fred M. Link specifies Eimac tubes is confirmation of the fact that Eimac tubes are first choice of leading electronic engineers throughout the world.

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DATA BOOK
SEC. 28 P. 101

SUBJECT: SUBSTITUTION OF ADDING MACHINE TAPE FOR CONTROL CHART DATA SHEET

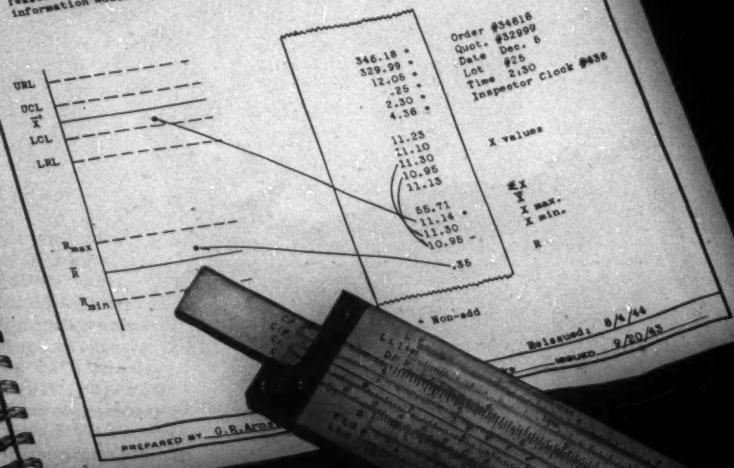
CONTROL CHART

As indicated on pages 100, 103 and 106 Forms #218 (n=10) and Form #227 (n=5) are available for recording $\bar{X}$ readings of sample lots.

This practice has been superseded at some inspection centers by direct recording of measurements on small manually operated adding machines. To begin a record the full job and lot data are listed on the adding machine tape using the non-add key. The individual pieces are then measured and immediately listed on the tape. When 5 (or 10) values have been taken the column is added (by the machine).

This tape is then torn off and clipped to the job board containing the control chart record sheet. Values of $\bar{X}$ and R are, of course, immediately plotted on the control chart.

This practice saves considerable time and its use is recommended wherever feasible. The appearance of the adding machine tape containing complete information would be as shown below.



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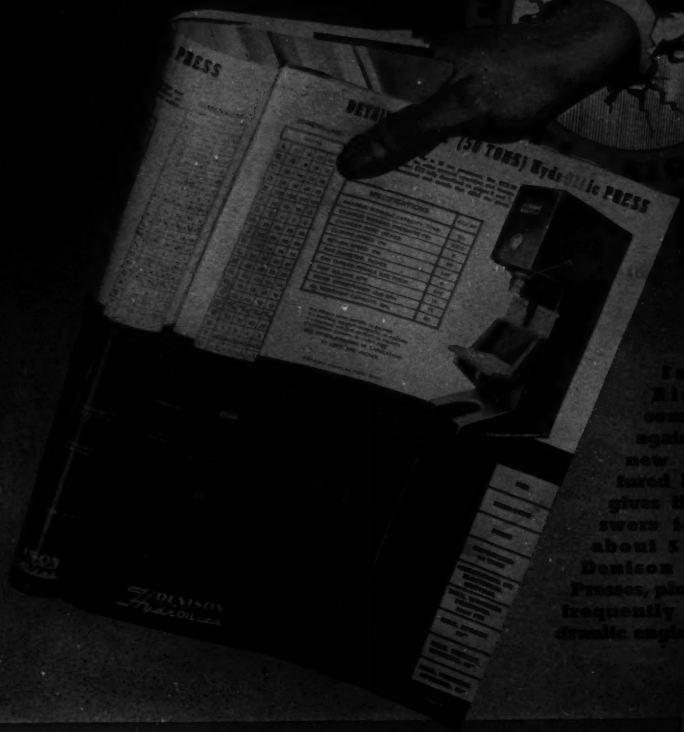

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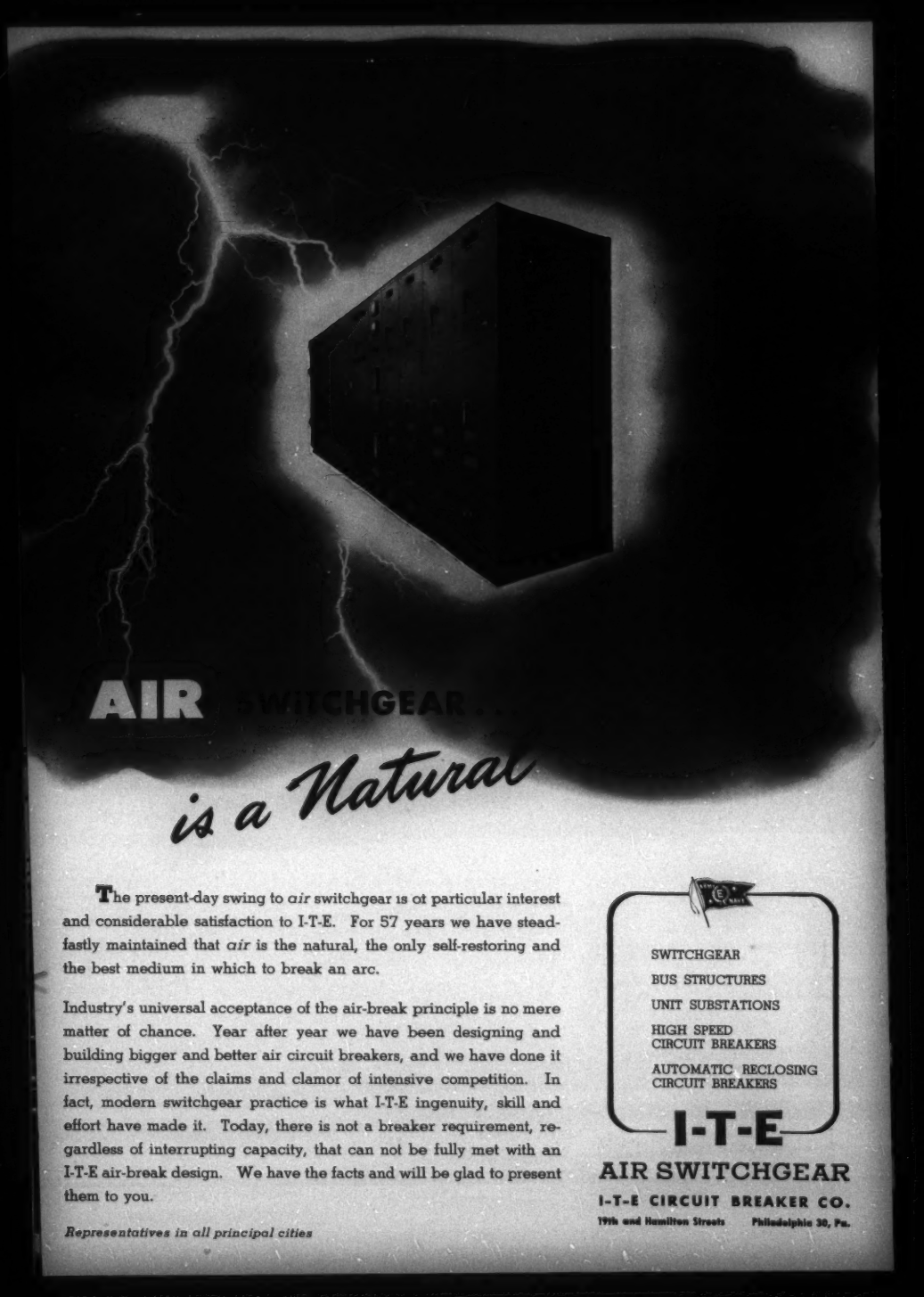

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